A DECISION TOOL TO EVALUATE BUDGETING METHODOLOGIES FOR ESTIMATING FACILITY RECAPITALIZATION REQUIREMENTS

THESIS

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AFIT/GEM/ENV/08-M09

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Abstract

The purpose of this research was to develop a decision tool to assist in the evaluation of facility recapitalization budget estimation models to determine which model was best suited for a particular organization. Specifically, this thesis sought to answer an overarching research question addressing the importance of recapitalization and the best method to estimate the facility recapitalization budget using the Department of Defense (DoD) as the subject of the research.

A comprehensive literature review revealed ten existing recapitalization model alternatives to consider for implementation. The methodology used to develop a decision tool was based on the Value Focused Thinking (VFT) approach. A panel of recapitalization program managers developed a value hierarchy to evaluate all potential recapitalization model alternatives.

The results of the deterministic and probabilistic analyses of 15 alternatives found that the proposed DoD model scored well in comparison to other alternatives. With slight modifications to the model according to the value hierarchy, the DoD can improve the performance of their recapitalization models. The H-Model, created specifically for this analysis, dominated all other alternatives and is recommended for implementation.

Acknowledgments

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Captain Krista Hickman

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A DECISION TOOL TO EVALUATE BUDGETING METHODOLOGIES FOR ESTIMATING FACILITY RECAPITALIZATION REQUIREMENTS

I. Introduction

One of the largest investments made in both the public and private sectors is in facilities and infrastructure. Modern and properly maintained facilities and infrastructure are directly linked to high quality of life, a good reputation, and the general success of a company or organization (BRB, 1998). However, because the result of poor maintenance and repair is not immediately visible, funding for maintenance and repairs is often sacrificed for more seemingly pressing obligations (Barco, 1994). Needed repairs often remain unfunded until a drastic event occurs such as a water supply line break, electrical outage, or roof leak. Without proper stewardship though, real property assets will deteriorate prematurely and fail to reach their designed service life. Therefore, one obligation of real property ownership is proper budgeting for both repairs and modernization. Yet, most of the available research on facility budget estimation models has been conducted strictly for maintenance budgets. Very few studies consider budget estimation models specifically created for recapitalization, which includes modernization and restoration. To address this issue, this thesis investigates existing budgeting models used to recapitalize assets and presents a decision model to determine the budgeting model best suited for an organization.

Background

The ultimate goal of asset stewardship is to ensure the correct balance is achieved between asset investment and other financial obligations (Vanier, 2001). Through adequate asset management, full service life can be achieved and operations can continue with minimal interruption. However, each organization has a unique perspective on proper asset stewardship, causing variations among respective budget estimation models.

There are several types of models for estimating facility maintenance and repair budgets. Neely and Neathammer (1991) classified the models as plant value methods, other formula-based methods, life-cycle cost methods, and condition assessment methods. Using a plant value method, the budget for maintenance and repair is estimated to be a percentage of the cost (in current dollars) to completely replace the facility with one of equal capacity (Leslie & Minkarah, 1997). Other formula-based methods include mathematical expressions with various factors, such as facility size, facility function, climate, location, and type of construction (Barco, 1994). Life-cycle cost methods estimate the maintenance costs over the expected service life by breaking down each facility into subsystems and estimating replacement costs for each system (Ottoman, Nixon & Lofgren, 1999). Condition assessment methods use physical inspections to determine the remaining service life of a facility and estimate the cost to repair any deficiencies (Earl, 1997). Variations of each basic model type are used throughout both public and private industries; however, there are unique challenges associated with managing assets in the public sector.

Organizations such as universities; various departments of federal, state, and city governments; and hospital complexes use public funds. Therefore, asset management in

the public sector is especially vital. Stewardship of public funds is a significant responsibility of public industry and the burden of accomplishing this task is enormous. The Building Research Board (BRB) made the following statements in a report:

> Public agency managers and elected officials, faced with the constant challenge of balancing competing public priorities and limited fiscal resources, often find it easy to neglect the maintenance and repair of public buildings. … The cumulative effects of wear on a facility are slow to become apparent and only infrequently disrupt a facility's users. … Facility managers are often poorly equipped to argue persuasively the need for steady commitment to maintenance. Underfunding of maintenance and repair is such a prevalent practice in the public sector that it has become in many agencies a *de facto* policy that each year compounds the problem as the backlog of deficiencies grows. … Neglect of maintenance can … cause long term financial losses as buildings wear out prematurely and must be replaced. Decisions to neglect maintenance … violate public trust and constitute a mismanagement of public funds. In those cases where political expediency motivates the decision, it is not too harsh to term neglect of maintenance a form of embezzlement of public funds, a wasting of the nation's assets. (BRB, 1991, p. 1-2)

Additionally, public sector organizations typically have a larger inventory of facilities to maintain, making asset management even more essential. For example, the Department of Defense (DoD), one of the world's largest organizations in terms of real property, operates about 571,900 facilities with a total replacement value of $650 billion (DoD, 2006). This large inventory of real property requires significant effort to plan and budget for operations, maintenance, restoration, and modernization.

Several studies have been conducted that investigate models for predicting facility maintenance budgeting requirements (Ottoman, 1997; Sharp, 2002; Jefson, 2005). Each study used different methodologies and the results varied. However, common aspects lacking in each research project were that the models were limited to maintenance predictions and did not investigate recapitalization models. Additionally, the studies did

not propose an original method that may be more appropriate for the public sector; furthermore, no general decision tools were created to assist decision-makers in the future as requirements evolve.

Definition of Terms

Before addressing the problem statement, it is necessary to explicitly define the specific levels of facility budgeting for the purposes of this analysis. There are three distinct areas of facility budgeting: operations, sustainment, and recapitalization. It is important to understand the distinction between them because the slight nuances in definition represent different budgeting philosophies. Sustainment and recapitalization are often referred to as SRM or Sustainment, Restoration, and Modernization. The scope of this research will focus just on the restoration and modernization portions of SRM which constitute recapitalization. Therefore, for the purposes of this analysis, the following definitions will apply (DoD, 2002).

<u>Operations.</u> This refers to day-to-day operational expenses. Typical items included in a facility operations budget are: utilities, annual service contracts, emergency services, transportation, and security.

<u>Sustainment.</u> This refers to the maintenance and repair activities on real property that are necessary to keep facilities in good working order. This includes regularly scheduled maintenance (replacing filters, lubrication of mechanical systems, etc.) as well as planned major repairs (roof replacement, painting, etc.). Sustainment items do not extend the service life of a facility; they simply provide the necessary maintenance and repair to ensure a facility reaches its intended service life. An important distinction is

that lack of proper sustainment results in lost service life that cannot be recovered except through recapitalization activities.

Recapitalization. This refers to major renovation or reconstruction activities (including replacement facility construction) needed to modernize facilities and prevent obsolescence. Recapitalization activities extend the service life of facilities or restore lost service life due to lack of sustainment. It does not include construction of facilities or infrastructure for new missions.

Problem Statement

Asset managers are expected to justify the costs of facility requirements against other competing requirements; however, there is a lack of research that compares recapitalization models and evaluates which method is best suited for a particular organization. To address this problem, this research will focus on several areas. First, to determine the importance of budgeting for recapitalization, the existing literature on the effects of underfunding facility maintenance and upgrades will be researched. Next, the existing literature on models that specifically focus on recapitalization will be summarized to determine what is being used in both the public and private sectors. Then a proper methodology to evaluate the best recapitalization strategy for an organization will be developed, resulting in the creation of a decision tool to assist in the evaluation of recapitalization models for an organization.

To conduct this research, a specific organization must be used; therefore, the subject of this research will be the DoD. Public Law 109-163, Sec. 352, states that the Secretary of Defense must submit to Congressional defense committees a report that

details the models used to prepare the budget requests for base operations support, sustainment, and facilities recapitalization (National Defense Authorization Act for FY06). Therefore, the models selected to estimate real property budgets are extremely important, especially for the DoD.

Research Objectives

The main objective of this research was to add to the existing knowledge on budget estimation methods by answering the question: Why is recapitalization important and what is the best method to estimate the facility recapitalization budget for the DoD? Because the methods used for recapitalization are standardized for every branch within the DoD, this thesis focused on models that can be implemented DoD-wide. To answer the main research question, the following secondary research questions were answered.

1. What are the long term causes and effects of under-funding the maintenance of facilities?
2. What methods currently exist and are used for estimating recapitalization requirements in both public and private sectors?
3. What is the appropriate methodology for determining the best recapitalization estimation method for the DoD?
4. What values are important to the DoD decision-makers for selection of the best recapitalization method?
5. What is the most preferred method for DoD facility recapitalization budget estimation?
6. What are the decision-makers' risk behaviors with regard to recapitalization models and do they have an effect on the preferred result?

Research Approach

The proposed methodology initially consisted of a literature review, focusing on academic journals and published DoD policy, to answer the first three questions regarding the effects of underfunding SRM requirements, the existing models designed for facility budget estimation, and the appropriate methodology for solving the decision problem. To answer the remaining questions, a panel of decision-makers from the DoD were consulted to determine their values and risk behaviors. Their values were incorporated into a decision tool that was used to analyze the performance of the recapitalization model alternatives and assess the influence of their risk behavior. The panel consisted of subject matter experts at the headquarters level from each branch of service and the DoD.

Assumptions

One major assumption in this thesis is that of probabilistic independence, which means that the probability of an event occurring has no bearing on the probability of another event occurring. This is important because probabilities and uncertainty are used in this thesis; therefore, assuming probabilistic independence allows the use of other statistical formulae. Other assumptions made in this thesis will be addressed as required within subsequent pages.

Scope

A Government Accounting Office (GAO) report revealed that the DoD did not have a comprehensive strategy for maintaining the services' infrastructure (GAO, 1997).

At that time, each service set its own standards for maintaining infrastructure, which resulted in non-comparable assessment ratings for the degree of criticality of requirements. To address these issues, the DoD developed the Facilities Sustainment Model (FSM) to standardize the budget calculations for sustainment only. The FSM method for sustainment funding is well accepted within the DoD and still in use today. Once that model was accomplished, the DoD developed the Facilities Recapitalization Model (FRM) to estimate restoration and modernization budget requirements. This method is currently in use today; however, the DoD plans to implement a newer model, called the Facilities Modernization Model (FMM), by the year 2010 to address some of the shortcomings of the current FRM. However, there are a variety of recapitalization model alternatives that the DoD could use to either improve their existing model or change to a new model. This study focused on those models that could be implemented for use within the DoD and used a decision analysis tool that incorporated the values of the experts within the DoD to select the best alternative.

Significance of Study

The efforts of previous researchers have helped to develop estimation models and advocate for the funding required to properly manage public assets. However, the DoD's existing recapitalization model is not fully supported at the executive and congressional levels. Program managers are not fully confident that the current model is best suited for the DoD and thus have had difficulty convincing leaders of the model's accuracy. Therefore, recapitalization funding is consistently less than is needed to fully modernize the DoD's facility inventory. The establishment of the decision tool as a result of this

thesis will help program managers advocate for and defend their decision to executive-level leaders about the most preferred method to estimate recapitalization funding. Another critical attribute of the decision tool is that it can be modified as values change and updated to evaluate future alternatives. This is important because advancements in technology and data-gathering methods are constant and the changing environment of the world mandates evolving priorities. Therefore, the best outcome may change as values and objectives change.

Organization

The rest of this thesis will present a literature review, methodology, results and analysis, and conclusions and recommendations. The literature review in Chapter II will provide a summary of existing literature pertaining to recapitalization models and a detailed description of the data collection and analysis methodology. An in-depth discussion of the methodology will be discussed in the third chapter, while the data and analysis will be included in the fourth chapter. Finally, Chapter V will summarize the results and make final recommendations.

II. Literature Review

Agencies with large facility inventories need to be committed to the overall cost of ownership. Over a building's entire service life, design and construction only constitute five to ten percent of the total cost of ownership, whereas operations, maintenance, and upgrades account for 60 to 85 percent of the overall cost (BRB, 1998). This means that agencies must carefully budget for both maintenance and recapitalization efforts for their facilities. A properly planned and timed recapitalization effort can save future maintenance costs (BRB, 1991). These factors combined explain why various agencies in both public and private sectors have spent enormous amounts of resources to research facility maintenance budgets and recapitalization strategies. Therefore, this chapter presents an overview of existing literature related to the research topic. Specifically, the literature review will cover six main areas: existing research on the causes and effects of deferred maintenance, a summary of existing recapitalization models, the current models used by the Department of Defense (DoD), the trends in model selection, the theory on decision analysis, and the Value Focused Thinking (VFT) process.

Deferred Maintenance and Repair Efforts

The causes and effects of deferred maintenance is a difficult topic to study. Most researchers studying facility management would agree that lack of proper maintenance leads to some damage that could have been avoided, some disruption of daily activities due to emergency repairs, and potential threats to the health and safety of a facility's

occupants (Kaiser, 1995). However, specific data that quantifies the cost of avoided emergency repairs or cost of occupants' health compared to the cost of undertaking a facility project are not available. Therefore, this section will start with a discussion of a facility's life-cycle and then review the existing literature regarding the causes and effects of deferred maintenance and repair on a facility's life-cycle.

Facility Life-cycle

A facility is designed and constructed to meet a specific need. Typically, it is designed to last at least 30 years and can last 100 or more years through proper maintenance and recapitalization (DoD, 1989). Figure 1 represents the normal facility life-cycle which compares performance to time and how maintenance practices influence service life. Performance, used here, means the facility's ability to meet its intended use.

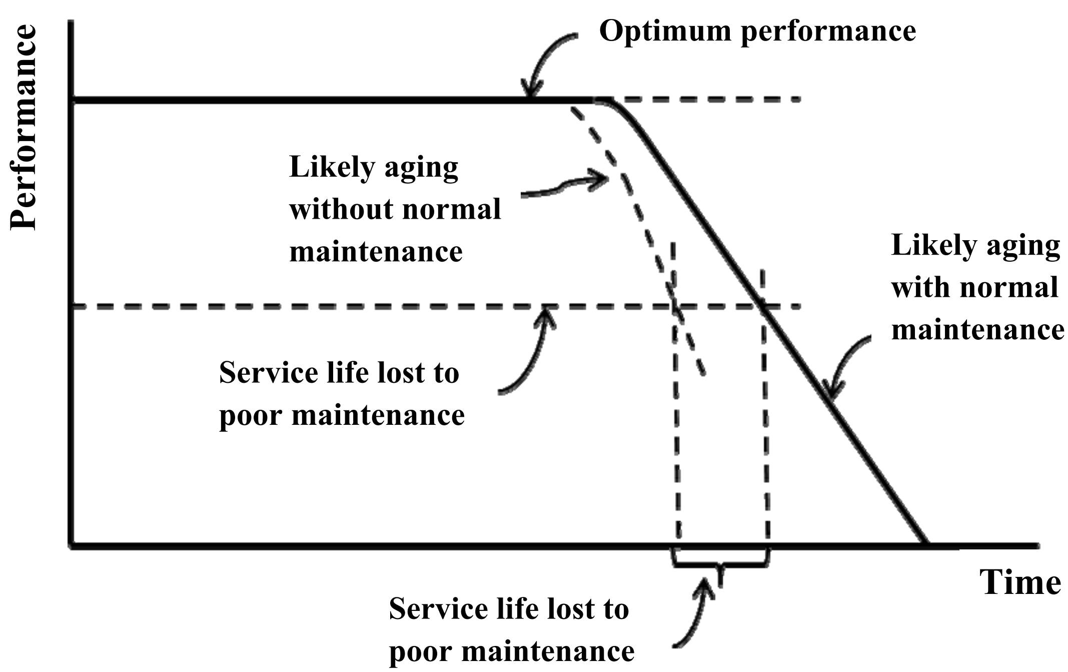


Figure 1. Maintenance Practices Influence Service Life (adapted from Lemer, 1996)

However, an agency's mission is not likely to last as long as the facility's service life, which often causes the facility's function to change. Therefore, the term obsolescence is used to describe a facility that can no longer meet its current needs and can result from a change in facility requirements or a deteriorated physical condition. Facility obsolescence is detrimental to an agency's mission. For instance, an aircraft hangar could be in very good physical condition, but if it cannot accommodate new types of aircraft, the facility is obsolete and needs recapitalization. There are four main causes of obsolescence: technological changes, regulatory changes, economic (social) changes, and changes in values or behaviors of people who use and own the facility (Lemer, 1996). Figure 2 shows graphically how a facility's performance can change with increased expectations. The lost service life lost depicted in Figures 1 and 2, which could be caused by many things including deferred maintenance and repair or obsolescence, are described in the next section.

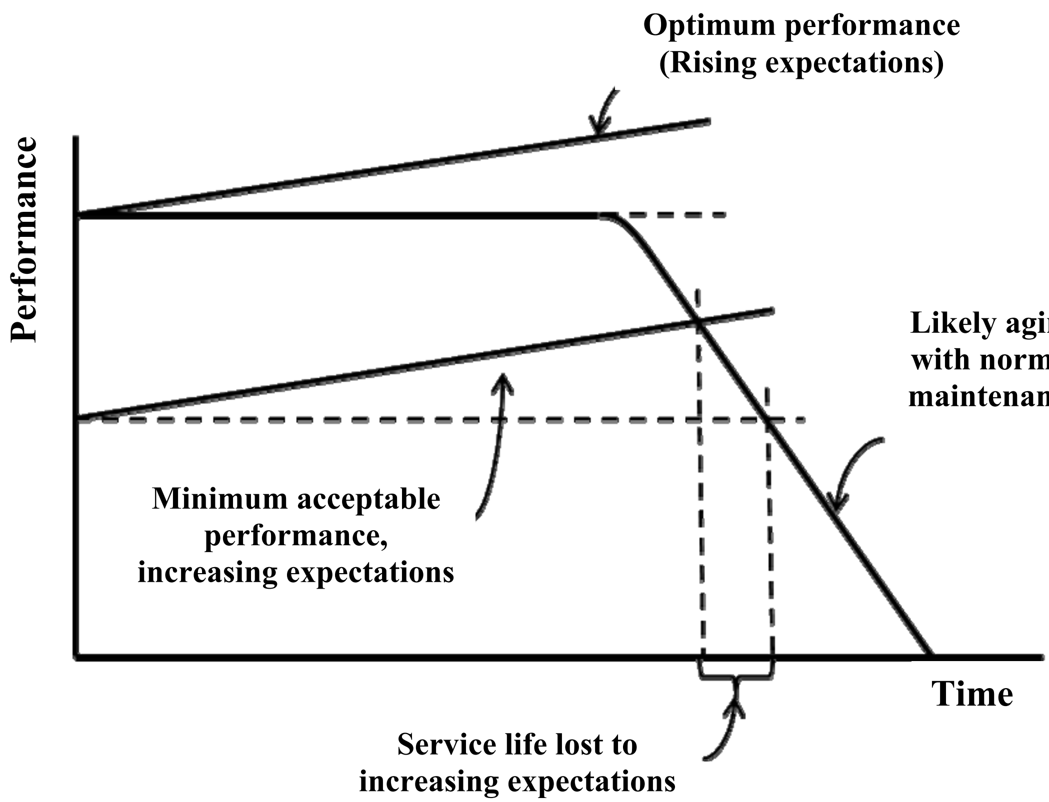


Figure 2. Expectations or Standards May Change with Time (adapted from Lemer, 1996)

Causes of Deferred Maintenance and Repair

There are three main reasons why maintenance is often deferred: cost, management obstacles, and institutional obstacles (BRB, 1991). The cost reason refers to either a lack of available funds or decision-makers deciding to spend money on other pressing needs rather than maintenance and repair efforts. However, the underlying issue is not just cost. It is also the lack of compelling evidence about both the effects of deferred maintenance and repair on facility life-cycle costs and the direct link between facility condition and an agency's ability to conduct its mission (BRB, 1998). This leads to the second main reason for deferred maintenance, management obstacles. Plenty of

data exist about the overall cost of the backlog of maintenance and repair projects; however, this information is often not useful or convincing enough to decision-makers who cannot visualize either the benefits of funding spent on maintenance or the consequences of deferred maintenance (GAO, 1997). Information that would be compelling to decision-makers is the future cost avoidance of spending money on certain facility projects or the risk assumed by not funding projects. However, cost avoidance data is not generally available (USACE, 1994). Finally, institutional barriers exist that make it difficult to predict maintenance costs. One example is that a facility's life-cycle is typically longer than the lifespan of a certain mission, which could cause frequent changes to a facility's use. These changes make it hard to provide a consistent budget for maintenance and repair and often cause facility obsolescence (USACE, 1994). Regardless of the cause though, there are several effects caused by deferring maintenance.

Effects of Deferred Maintenance

Most research on the effects of deferred maintenance is qualitative in nature. There are case studies about emergency repairs that could have been avoided if certain maintenance was not deferred or if certain repair projects were funded (BRB, 1991). However, most repair project justifications state that the project will prevent potential sewage back-ups, roof leaks, water-line breaks, etc., that might occur in the future. Obtaining data about the estimated costs that are likely to be avoided by providing adequate maintenance takes considerable effort to obtain and are unavailable in existing research (USACE, 1994). Determining the proper amount of funding to allocate for

maintenance and repair is another issue, to be covered later in this chapter. However, the worst result of deferred maintenance, without a recapitalization effort, is facility obsolescence and eventually failure.

One unique study on facility deterioration was conducted using systems dynamics, which is a methodology that compares complex interrelationships between different related entities through mathematical simulation. Jefson (2005) examined the dynamic relationship between maintenance actions, budgets, facility degradation, and serviceability over the lifespan of a building. The major finding in his research is that in order for facility maintenance and repair to be effective, it must be executed on time or else the synergistic decline of serviceability will be uncontrollable. Once degradation starts, it is almost impossible to control and can only be combated through recapitalization efforts (Jefson, 2005).

Early and consistent investment in facility maintenance and repair can prevent unnecessary wear and tear and avoid hard-to-measure consequences of emergency repairs, mission disruption, and employee health. If maintenance is deferred, a major recapitalization effort that was not planned will often be needed to correct the deficiencies. Examples of recapitalization efforts might be the replacement of an air conditioning system or a roof before they have reached their useful lives, a renovation due to damages caused by leaking water, or complete facility replacement. Figure 3 depicts graphically how recapitalization affects a facility's life-cycle. Accurate budgeting methods for both sustainment (maintenance and repair) and planned recapitalization (modernization or renewal), along with decision-maker commitment to providing the funding, are crucial for proper facility stewardship. Much research has

been conducted by both public and private agencies of various sizes on budget estimation models for sustainment and limited research has been done on recapitalization models; both types of models will be discussed next.

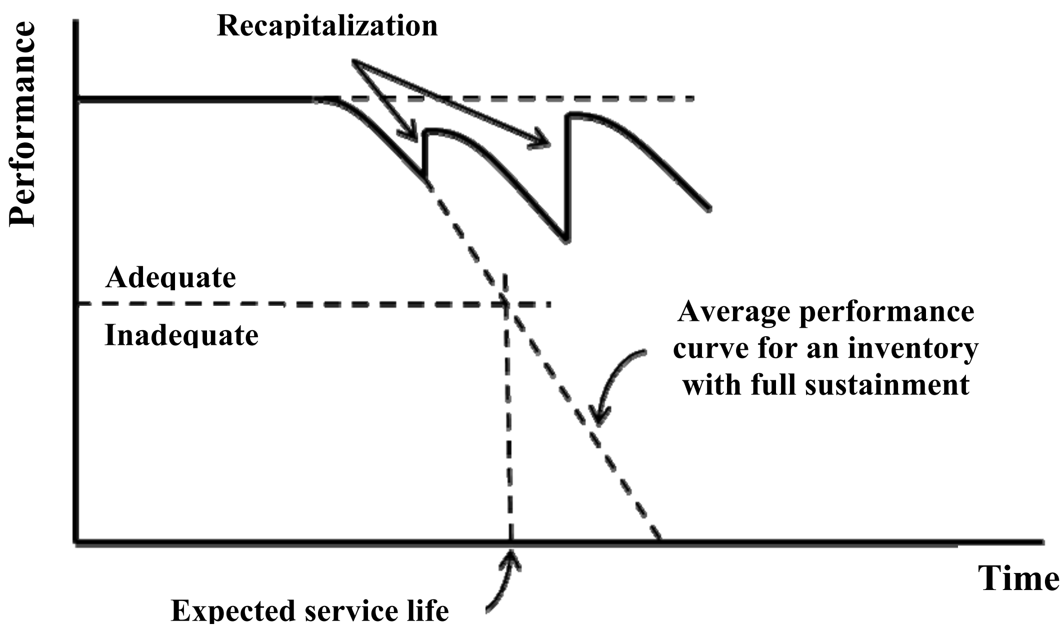


Figure 3. Facility Life-cycle with Sustainment and Recapitalization (adapted from DoD, 2002)

Recapitalization Models

Recall from Chapter I the distinction between sustainment (maintenance) and recapitalization. Sustainment refers to those activities conducted to keep facilities in good working order, such as scheduled pavement repairs and roof replacements. Any activities that modernize or extend the service life of a facility would be considered recapitalization. Usually, recapitalization will extend the service life of a facility.

However, when a recapitalization effort is undertaken due to deferred maintenance, the desired outcome will be to restore lost service life. This section includes a summary of recapitalization models used in industry and within the DoD and provides an overview of model selection trends.

Industry Models

Several researchers have attempted to categorize the various models available to estimate facility budgets. A summary of these researchers and the model classifications they created are shown in Table 1. It is important to note that both sustainment and recapitalization should be budgeted for separately but applied together in practice to ensure proper facility stewardship (DoD, 2002). However, the distinction between budgets specifically for operations, sustainment, and recapitalization is often not clear; therefore, only researchers who have made the distinction between sustainment work and recapitalization work are used in this paper. Since individual models often do not fit neatly into one of the categories shown in Table 1, three main categories will be used that broadly cover each type of model:

1. Formula-Based Methods
2. Life-Cycle Methods
3. Condition Assessment Methods

These three main categories are discussed in more detail in the remainder of this section.

Table 1. Summary of Facility Budget Model Categories by Researcher

Researcher(s)	Method Classification					
	Facility Value	**Formula (Depreciation)**	**Life Cycle**	**Condition Assessment**	**Project Backlog**	**Facility Size**
Barco, 1994	X				X	X
Kaiser, 1995	X	X	X			
Leslie and Minkarah, 1997	X			X		X
Ottoman, 1999	X	X	X	X		
Lufkin, Desai, and Janke, 2005	X	X		X		

Formula-Based Methods

Formula-based methods assume that the required annual funding can be estimated using a mathematical formula. The formulas are typically algebraic formulas, multiple formula algorithms like regression, or neural network simulations based on historical data (Christian, 1997). The formulas rely on current data to be accurate and usually include computer software. Variables that are often included in a formula include facility type, location, age, and type of construction (Kaiser, 1995). Historical data on maintenance costs or project backlogs are sometimes included as well. Almost every model could be considered a formula-based model because virtually all of them involve a mathematical expression; however, models that focus mostly on life-cycle costs or condition assessments will be discussed in later sections.

Formula methods have both advantages and disadvantages. One major advantage of formula methods is that they are less data intensive than life-cycle and condition assessment methods, which makes them more appropriate for organizations with large facility inventories. The major disadvantage is that most formulas do not account for the facility's existing condition. Formula methods often include the year of construction; however, that is only a proxy measure for condition. Because the actual condition is not assessed in a formula method, the exact amount required to recapitalize is unknown and the model result is a rough estimate. There are two main categories of formula based models that are most commonly used: facility value models and depreciation models, which will be discussed in the next section.

Facility Value Methods

The most common formula-based method is calculated using facility value. The premise of the method is to estimate either the sustainment or recapitalization budgets by taking a certain percentage of the value of either a facility or an inventory of facilities. There are two common ways to estimate facility value: current plant value (CPV) and plant replacement value (PRV). There are slight variations to the CPV and PRV equations; therefore, the simplest definitions are used from Barco (1994).

The CPV method uses the original cost to construct the facility and transforms that cost to present year dollars to estimate the budget. This method requires accurate data on initial construction costs plus the cost of any recapitalization efforts and some method of asset depreciation. CPV is commonly used in the private sector where a business tracks the depreciation for tax purposes; therefore, it is not often used in the

public sector (Barco, 1994). Another way to assess the current value would be to conduct real property appraisals; however, with a large facility inventory, this is often not feasible. The annual budgets for sustainment and recapitalization are then calculated by:

$$\text{Annual Budget Amount} = X\% * \text{CPV} \tag{1}$$

where an appropriate range for X% is 2 to 4 percent (BRB, 1991).

PRV is the cost to completely replace a facility with one of similar size and capability. The PRV method uses the facility's size and multiplies it by a current cost per unit to construct a similar facility at the same location. In its simplest form, the equation for PRV is (Ottoman, Nixon & Lofgren, 1999):

$$\text{Annual Budget Amount} = X\% * \text{PRV} \tag{2}$$

where an appropriate range for X% is 2 to 8 percent (BRB, 1991). The PRV for a single facility and the total PRV for an inventory of facilities are calculated as follows (Barco, 1994):

$$\text{Facility PRV} = (\text{facility size}) * (\text{unit cost of facility type}) * (\text{area cost factor}) \tag{3}$$

$$\text{Total PRV} = (\text{Total facility PRV}) + (\text{New Construction Cost}) - (\text{Demolition}) \tag{4}$$

The PRV method is useful for organizations with large facility inventories that are spread out in many geographical areas, which is why many public agencies use some form of PRV for their estimations. A comparison of the percentages used to conduct budget estimates is summarized in Table 2. Funding levels vary by organization due to different priorities placed on budget needs.

Table 2. Annual Investment Levels as a Percent of PRV (adapted from DoD, 1989)

Organization	**Recapitalization (%)**	**Sustainment (%)**	**Total (%)**
DoD	1.6	1.4	3.0
Other Public Agencies (transportation, utilities, etc.)			4.5
Colleges and Universities	6.9	1.5	8.4
Major Private Corporations	5.4	3.5	8.9
Non-DoD Government entities	8.2	1.4	9.6

Another formula-based method is the Sherman and Dergis formula (Sherman & Dergis, 1981). This formula is expressed using the following equation, where facilities are assumed to have a 50-year life span (Ottoman, Nixon & Lofgren, 1999):

$$\text{Annual Recap Budget} = 2/3 * BV * BA/1275 \tag{5}$$

where BV = building value adjusted to the original cost

BA = building age corrected for partial (>10% of BV) or building renewal cost

2/3 factor = building renewal constant and is based on the assumption that renewal should be no more that 2/3 the cost of replacement

1275 factor = the sum of the years digits for a based on an age weighting constant for a 50 year life-cycle (50+49+48+ … +3+2+1 = 1275)

This formula method also uses a simplified life-cycle analysis because the annual budget amount increases as the facility ages and the BA factor accounts for any facility renovations. One variation of this method was proposed by Phillips (Ottoman, Nixon & Lofgren, 1999). His model classifies facility systems as either 25-year systems (roofing

and HVAC) or 50-year systems (walls, conveyances, electrical, plumbing, and fire protection). The formulas are as follows (Ottoman, Nixon & Lofgren, 1999):

Renewal Allowances (25 yr) = (BA/325) * Replacement cost of systems (6)

Renewal Allowances (50 yr) = (BA/1275) * Replacement cost of systems (7)

BAadj = (renovated fraction*years since renovation)+(unrenovated fraction*BA) (8)

where the constants 325 and 1275 represent the sum of the year's digits for a max age of 25 or 50 year life spans.

Depreciation Methods

Another common formula based model is depreciation. Lufkin (2005), an advocate for the depreciation method, stated that even though condition-based assessments are more defensible, methods of economic depreciation are useful approaches for large organizations. The key assumption made for the use of depreciation models is that the actual loss in value of a facility equals the required renewal costs and can be estimated by using economic depreciation models (Lufkin, 2005). There are three general patterns of facility depreciation consisting of straight-line, accelerated, and decelerated depreciation, which are depicted in Figure 4 (Green, Grinyer & Michaelson, 2002; Fraumeni, 1997; Schmalz & Stiemer, 1995). While straight-line is the simplest depreciation method, there is literature that supports its use (Green et al., 2002). Green, Grinyer, and Michaelson (2002) used simulation tools to evaluate under what circumstances the straight-line method would be adequate. The researchers found that, due to the inherent uncertainty in approximating economic depreciation, the straight-line

method is a suitable proxy for other methods; however, at service lives of over 15 years, the method's accuracy declines, which is also true of other depreciation methods.

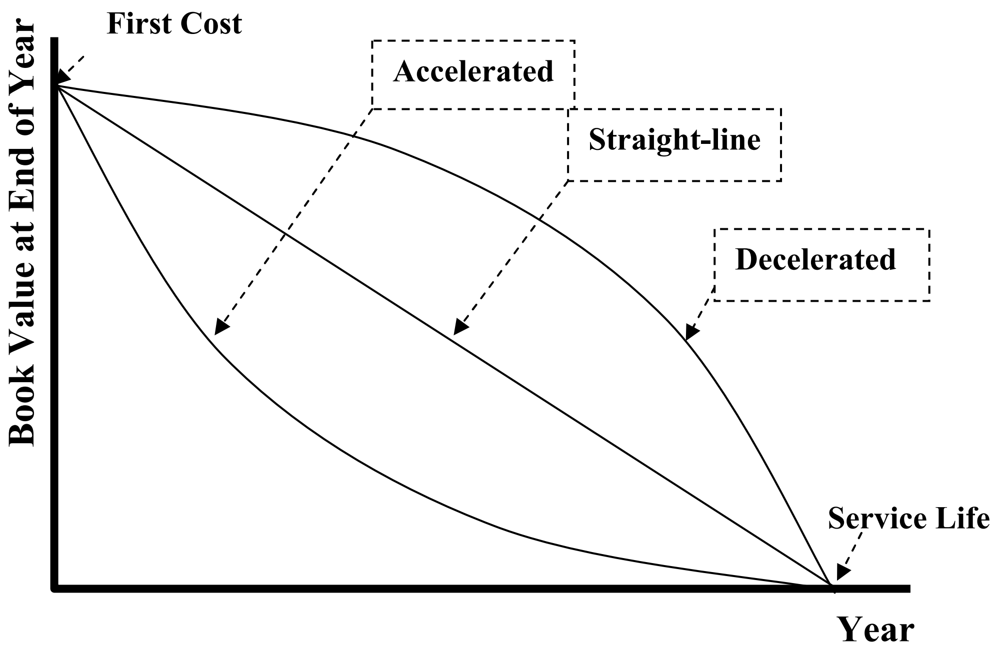


Figure 4. Comparison of Depreciation Methods (adapted from Eschenbach, 2006)

Accelerated methods include any pattern that allows more depreciation in the early years of an asset's life than at the end. In contrast to the previous research on straight-line depreciation, Fraumeni (1997) presented an overview of empirical research on depreciation and found that assets, in general, depreciate in a curved pattern. Results for various types of facilities indicated an accelerated curve was best for 14 industries, a straight-line pattern was best in 5 industries, and a decelerated curve was best in 3

industries. Overall in Fraumeni's study (1997), accelerated patterns appeared to be the best approximation of depreciation of structures.

The final depreciation method is decelerated, an example of which is the one-hoss-shay method which approximates lower depreciation rates early on in an asset's life. This is not ideal for tax advantages; however, the pattern most closely matches the typical service life decline of a facility (Schmalz & Stiemer, 1995). Taubman and Rasche (1969) concluded that economic depreciation of a facility occurs more slowly than straight-line and that the one-hoss-shay method was a better approximation than the other methods. Additionally, another study found that when businesses used straight-line depreciation methods for facilities, reported depreciation was less than economic depreciation, thereby providing additional evidence that structures depreciate more in later years than in the early years (Bar-Yosef and Lustgarten, 1994).

Figure 4 represents the depreciation of a facility until it has no service life left; however, it is unlikely that a facility will be used until it completely fails. Therefore, there is usually a predefined level of minimum acceptable performance, as Figures 1-3 indicate, which is around 30-40 percent (Bradley, 2006). This indicates the potential salvage value of the facility; once the facility reaches this minimum performance level, it can either be renovated or demolished and re-built if needed. The salvage value can be realized through recycling of materials by careful deconstruction or the debris can be disposed of without gaining any value from the materials (Guy, 2006).

Life-Cycle Methods

The life-cycle approach estimates recapitalization costs by breaking down the facility into components (structure, roofing, electrical, plumbing, HVAC, etc.) and individually assessing the life-cycle of each component. It is often used to predict operations and maintenance budgets, but it can also be used for predicting recapitalization costs by tracking when systems are expected to be replaced or become obsolete. Much research has been done on life-cycle costs; therefore, cost data is readily available using R.S. Means costs and Dodge Construction Systems Costs for construction costs (Ottoman, 1997), or U.S. Army Corps of Engineers (USAACE) cost estimating manuals for life-cycle costs (Neely & Neathammer, 1991).

The BUILDER engineered management system is a life-cycle model developed by the U.S. Army Construction Engineering Research Laboratory (USACERL) (Uzarski & Burley, 1997). The model predicts facility requirements based on inventory data and condition prediction for 12 basic facility systems. This is an involved process that requires data entry on the details of each facility and facility system in the inventory along with the results of condition assessments. The BUILDER program creates deterioration cost curves and renewal costs which enables planners to predict the most cost-effective point to conduct renewal projects (Uzarski & Burley, 1997).

Another unique model that was developed to forecast renewal funding needs focuses on transferring construction costs to renewal costs based on data accumulated over a facility's service life (Leslie & Minkarah, 1997). This method gathers historical data on the cyclic deterioration loads of the different types of facilities; based on this

data, the original construction cost is multiplied by factors that account for previous maintenance, facility age, etc. The basic formula is:

$$\text{Renewal Cost} = \text{Construction Cost} * \text{factor } 1 * \text{factor } 2 \text{ etc.} \tag{9}$$

This is a very data-intensive model that requires expert cost estimators or expert software to assist in developing the renewal cost factors.

There are some challenges to implementing life-cycle methods for budget predictions. Even though there is data on how long facility components should last, accurate maintenance data on each facility is required to use the method to predict future renewal costs. The challenge for large organizations, especially those in the public realm or those that are geographically separated, is that accurate, standardized data collection is not available and is very expensive to obtain (BRB, 1991). Therefore, generally speaking, life-cycle cost analysis is best applied for recapitalization planning through assisting decision-makers in choosing preferred alternatives, rather than as a budget estimating tool.

Condition Assessment Methods

The basis of using condition assessment methods is that an agency can predict renewal needs by systematically evaluating its real property assets to determine the remaining useful life and what upgrades are needed (Rugless, 1993). Routine, standardized facility inspections are required to implement a successful condition assessment program. To ensure all facilities in the inventory are held to the same standard, each inspector must have the same training so that they know how to rate each facility component. This is imperative because all the data must be put into a central

database for comparison and analysis. This can be a cumbersome and expensive process to train inspectors and conduct the inspections. However, technological advancements have made this process easier (Geldermann & Sapp, 2007).

There are several examples from the literature regarding the implementation of a condition assessment system. One company with 2000 facilities decided to implement the condition assessment process, and it took 15 months to implement (Rugless, 1993). This company was pleased with the results because it provided them with accurate data of their facilities' conditions. Additionally, the Department of Energy, which has about 25,000 facilities, decided to implement a condition assessment procedure and the planning alone took 18 months (Earl, 1997). However, problems arose during implementation due to computer system compatibility and resistance from facility managers (Earl, 1997). This case study showed the difficulties that can occur by applying condition assessments in a public setting, especially in an agency the size of the DoD. However, the U.S. Army Construction Engineering Research Laboratories developed the BUILDER tool for managing large inventories of assets, which provides a consistent and repeatable way to assess building conditions (Uzarski & Burley, 1997). The BUILDER model could be feasible for DoD-wide use.

A specific example of a condition assessment model (which is also a life-cycle method) is the Applied Management Engineering (AME) method (Ottoman, Nixon & Lofgren, 1999). This method uses their facility condition information system (FCIS) to develop short and long term plans for maintenance and to track project backlogs. The renewal needs are estimated by a combination of facility assessment and life-cycle analysis that provides estimates on the remaining useful life, called years to renewal. A

basic assumption of this model is that the project backlog will be reduced within 5 years because 5 years is the assumed renewal frequency. This is an important limitation of the AME model because many organizations cannot reduce their project backlog every 5 years, especially large organizations like the DoD.

Department of Defense

The DoD operates and maintains about 80% of the total U.S. federal property, plant, and equipment inventory and spends slightly over two thirds of federal appropriations for acquisition of physical assets (GAO, 1997). Thus, the DoD has invested in and conducted vast research into its own practices and developed several models for its use. Osborne, as quoted in Barco (1994) stated that, "At all levels of government, accounting records almost entirely ignore what assets are owned, their state of repair, and their value." This and other associated GAO reports found that the government needed improvements in their facilities management, which led to research on the development of better budget prediction models (GAO, 2000). As a result, the DoD implemented a new strategy of developing models that predicts what they should be spending on facilities. The premise of this strategy is to develop models for the three areas of facility expenses (operations, maintenance, and recapitalization) and compare the model output with what was allocated to determine benchmarks and necessary spending limits. First, the DoD developed the Facilities Sustainment Model (FSM) which was implemented DoD-wide. This model is now widely accepted by Congress and, due to its credibility, maintenance is routinely funded at 95% of the model output value. This level

of standardization for DoD sustainment budgets was a crucial step towards progress and a stepping stone to developing a standardized recapitalization model.

Based on a report by the Civil Engineering Research Foundation (CERF), the Air Force level of investment in sustainment (3% of the PRV) is consistent with other public and private organizations; however, the CERF report also stated that all areas are under-spending (Ottoman, Nixon & Chan, 1999). Under-spending in sustainment leads to increased recapitalization requirements. A report conducted by the DoD in 2002 summarized how recapitalization is currently calculated. This report recommended use of the Facilities Recapitalization Model (FRM), which is calculated by (DoD, 2002):

$$PRV = \text{Facility Area} * CCF * ACF * HRA * P\&D * SIOH * CONT \tag{10}$$

where CCF = Construction Cost Factor

ACF = Area Cost Factor (accounts for geographic location)

HRA = Historic Requirement Adjustment

P&D = Planning and Design factor for medical (13%) or non-medical (9%)

SIOH = Supervision, Inspection, and Overhead costs factor (typically 6%)

CONT = Contingency fund factor (typically 5%)

The report stated that the FRM is the solution to providing adequate renewal budgets and that existing alternative methods could not provide comparable levels of coverage (DoD, 2002). Additionally, the DoD uses the FRM metric to track investment levels in recapitalization each year. The recapitalization metric is calculated by the following formula (DoD, 2002):

$$\text{FRM Metric (years)} = PRV(\$) / \text{Investments (\$/year)} \tag{11}$$

The FRM is only calculated for facilities in the active inventory and excludes facilities scheduled to be demolished. The investment figure in the denominator is the sum of recapitalization funding from all different sources, including Military Construction (MILCON) funds used for renovation and replacement facilities, planning and design funds, and other minor construction funds (DoD, 2002). The current recapitalization rate metric is 67 years, which means that the average service life of DoD facilities is 67 years and the budget investment level should reflect this figure.

However, a new model called the Facilities Modernization Model (FMM) is planned to be implemented by the DoD in 2010. The formula for this model is (DoD, 2007):

$$\text{Recap Rate (\%)} = \text{Investments (\$/year)} / \text{FMM Benchmark (\$/year)} \qquad (12)$$

where

FMM Benchmark = (PRV * T) / Estimated Service Life (based on facility type)

$T = D * \{1 + [R(1-D)/(1-R(1-D))]\}$

D = Depreciation Rate for pure renovation = 60%

R = % of investment on replacement construction (based on historic data)

The key assumptions in this model are that facilities (1) can be modernized through either repair or replacement, (2) usually possess a residual value at the end of their useful service lives, and (3) can either be modernized with renovations or demolished (DoD, 2007). A typical rule of thumb (with the exception of historical facilities) is that a facility should be replaced in lieu of renovation if the estimated renovation costs exceed 70 percent of the facility's replacement value. Based on the assumption that facilities can be recapitalized with repairs or replacement, the proposed facility depreciation is based on

the following straight-line method shown in Figure 5, which also clarifies some of the variables in the FMM equations.

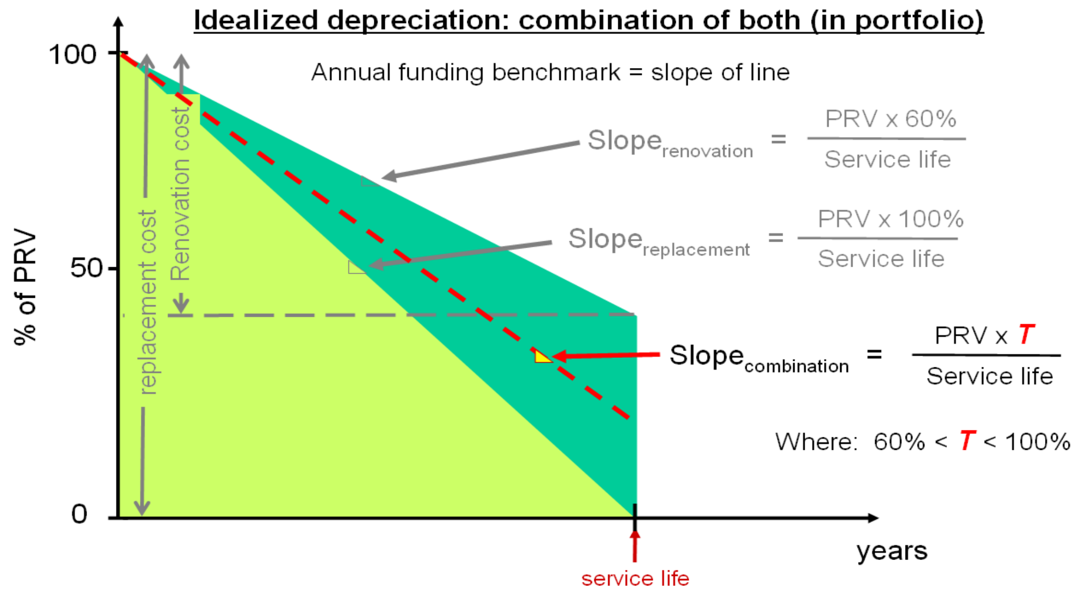


Figure 5. Idealized Depreciation Method for FMM (DoD, 2007)

A recent report conducted by DoD contractors looked at a comparison of DoD and industry recapitalization methods (Adams & Mercer, 2007). In general, the report found that firms with large facility portfolios tend to use formula-based approaches and estimate the recapitalization budget at 1.5 to 3 percent of the CRV. However, most private firms have more flexibility in funding sources for recapitalization and have a much shorter planning horizon than the DoD, thereby making it difficult to directly compare. Additionally, a trend among major corporations is to lease some or all of their

facilities; therefore, their idea of recapitalization is moving to a new facility once their current one becomes obsolete (Adams and Mercer, 2007).

Summary of Recapitalization Models

In 1997, Ottoman conducted a comparative multi-attribute decision analysis on available sustainment investment models and which model was best suited for the US Air Force (Ottoman, 1997). This thesis report will be similar, except it will focus on recapitalization models only that can be applied DoD-wide. In addition to the DoD's FRM and FMM, there are many other models that could be used for the DoD, including variations of existing models. A summary of the models found from this literature review are listed in Table 3 according to their classification.

Table 3. Summary of Recapitalization Models Found From Literature Review

MODEL	Formula Based	Estimating Approach Condition Assessment	Life-Cycle
CPV	X		
PRV	X		
Dergis-Sherman	X		
Facilities Renewal	X		
Depreciation	X		
BUILDER		X	X
Renewal Factors			X
AME		X	
FRM	X		
FMM	X		

Model Selection Trends

Selecting the best model is at the discretion of the decision-makers who are responsible for the stewardship of their facilities. There are many models available and many reasons why a particular model would be considered best suited for a given organization. The progression of research into recapitalization budgeting models shows a transition from PRV methods to more data intensive condition assessment and life-cycle approaches. The first research into maintenance and repair (M&R) methods dates back to 1950 when Kraft stated that budgets should be based on present replacement costs (Ottoman, Nixon & Lofgren, 1999). The next trend was led by Sherman and Dergis (1981), who stated that "…all construction factors – size, complexity, materials, special facilities, and so on – are all conveniently reflected in construction cost." Therefore, at that time, a simple PRV or CPV calculation that accounted for the facility's age was sufficient for budgeting purposes. From that point, most research was centered around facility characteristics and their impact on replacement and renewal costs. The BRB's research into this topic revealed the following important building characteristics that should be considered for accurate budgeting: building size, type of finishes, age, condition, climate, location, level of pervious maintenance, and intensity of use (BRB, 1991). Findings from other key researchers like Kaiser (1995) and the BRB (1998) agree that those factors are important in determining facility budgets.

With ample research conducted thus far, mostly on the sustainment budgets, a consensus of opinion is based on the following three conclusions (Ottoman, Nixon & Chan, 1999):

1. Deferral of M&R will result in higher M&R costs in the future

2. Certain facility characteristics are indicators of the level of renewal required
3. The life-cycle of facilities has been well researched and is generally predictable, and may be used to approximate expected M&R costs in a facility

The ultimate selection of the best model for the DoD is a hard decision with multiple objectives to consider. Therefore, decision analysis methods to assist in model selection will be reviewed next.

Decision Analysis

The theory behind decision analysis is that careful application of sound techniques leads to better decisions that are consistent, structured, transparent, logical, and auditable (Clemen and Reilly, 2001). Decision analysis is appropriate when the nature of the decision being confronted is complex, has uncertain outcomes depending on the alternative chosen, has different conclusions based on different perspectives, and often has multiple, competing objectives (Clemen and Reilly, 2001). The nature of the problem being addressed in this thesis meets all these characteristics with the added attribute of being an executive/strategic level decision. There are five steps to a strategic decision making process (Kirkwood, 1997):

1. Specify the various objectives (values) and scales for measuring achievement of the objectives
2. Develop alternatives that could meet the objectives
3. Determine how well each alternative meets the objectives
4. Consider tradeoffs among the objectives
5. Select the alternative that best achieves the objectives, taking uncertainties into account

There are various decision techniques that can be used to evaluate alternatives. The Analytical Hierarchy Process, linear programming, and decision trees were all considered as potential decision methodologies; however, these were ruled out in favor of a more straight-forward strategic process that incorporates the values of the decision makers. The next section will provide an overview of two well known strategic decision analysis processes, Value Focused Thinking (VFT) and Alternative Focused Thinking (AFT), and select the most appropriate decision making technique for this study.

VFT vs. AFT

Value Focused Thinking (VFT), as the name suggests, focuses on the values of the decision-maker as the decision criteria. Values are defined simply as "what we care about" and "as such, should be the driving force for our decision making" (Keeney, 1992). As a basic definition, VFT can be considered a "structured method for incorporating the information, opinions, and preferences of the various relevant people into the decision making process" (Kirkwood, 1997). Focusing on values instead of alternatives, as is usually the case, enables the decision-maker(s) to think more creatively about a problem and facilitate the inclusion of any alternative that could meet the objectives. There are fewer constraints on alternatives considered through the VFT process as opposed to Alternative Focused Thinking (AFT), which is the usual decision analysis procedure (Keeney, 1992). The general steps in both processes are similar with the exception of the alternatives creation step, as illustrated in Table 4. This slight difference is important because the alternatives are identified in AFT before selection criteria are established. This makes AFT a quicker process because it is limited to known

alternatives; however, other viable options could possibly exist. Figure 6 provides an overview of VFT and shows the benefits of using the process. The decision-maker can be more confident in the results of VFT because it is based on a comprehensive analysis of all viable alternatives. Therefore, for this thesis, VFT will be used to generate values and alternatives for the best recapitalization method for the DoD.

Table 4. Comparison of AFT and VFT (Keeney, 1992)

Steps in AFT	Steps in VFT
1. Recognize a decision problem	1. Recognize a decision problem
2. Identify alternatives	2. Specify values
3. Specify values	3. Create alternatives
4. Evaluate alternatives	4. Evaluate alternatives
5. Select an alternative	5. Select an alternative

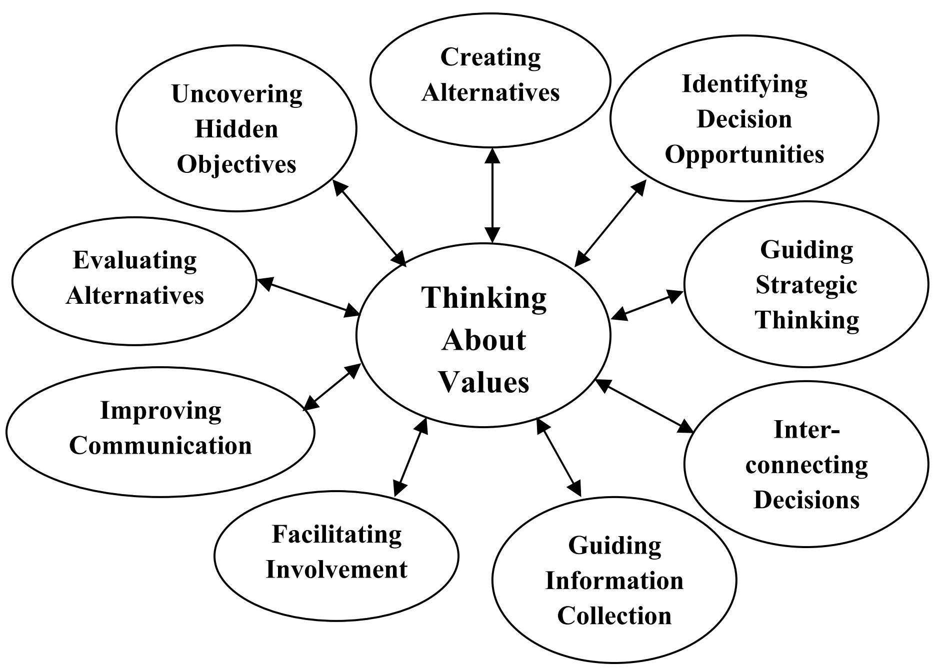


Figure 6. Overview of Value Focused Thinking (Keeney, 1992)

VFT Process

The five basic VFT steps shown in Table 4 can be broken down further into a ten-step process as shown in Figure 7. The first step, problem identification, is critical. The problem defines the scope and must be worded correctly so as not to limit possible alternatives. If the wrong problem is chosen or if it is worded incorrectly, the decision-maker's time and effort could be wasted. The right solution to the wrong problem is useless.

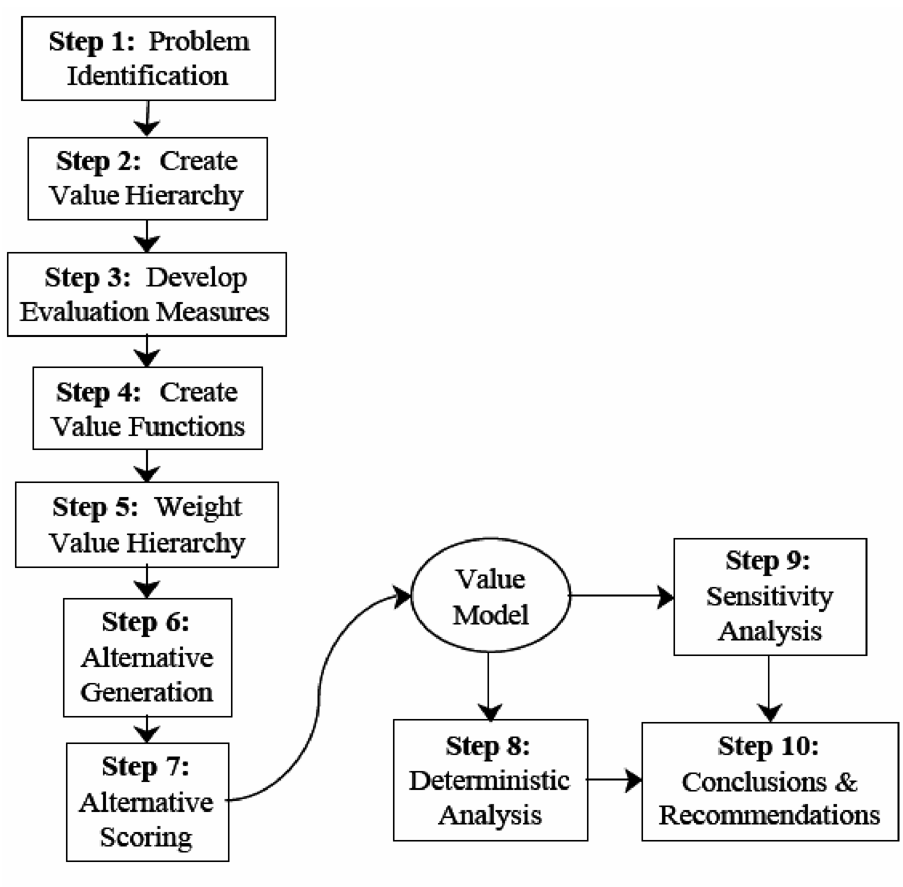


Figure 7. Ten Step VFT Process (Shoviak, 2001)

After the problem is identified, the decision-makers' values are determined and organized into a value hierarchy (see generic hierarchy in Figure 8). The hierarchy must possess the following characteristics: completeness, non-redundancy, preferential independence, operability, and small size (Kirkwood, 1997). Completeness means that the hierarchy must contain all the objectives or values that need to be considered to make the final decision; it must be collectively exhaustive. Non-redundancy means that the values in each level of the hierarchy cannot overlap; in other words, no two values can measure the same thing. This is sometimes referred to as mutually exclusive. Preferential independence means that, when evaluating the alternatives, the degree of attainment of one objective cannot change the degree of attainment of another objective. In other words, an alternative's score on one value must be the same regardless of the scores of the other values. Operability means the hierarchy is easily understood by anyone who needs to use it. Small size is included for simplicity and communication purposes. The hierarchy must be large enough for it to be complete, but small enough to be operable. All these characteristics are necessary and assumed to be true in order to use the additive value function in later steps. In addition to these five characteristics, Keeney (1992) includes three additional characteristics: essential; must be a fundamental quality of the decision, controllable; only objectives that can influence the best alternative should be included, and measureable; there must be a way to measure the degree of attainment.

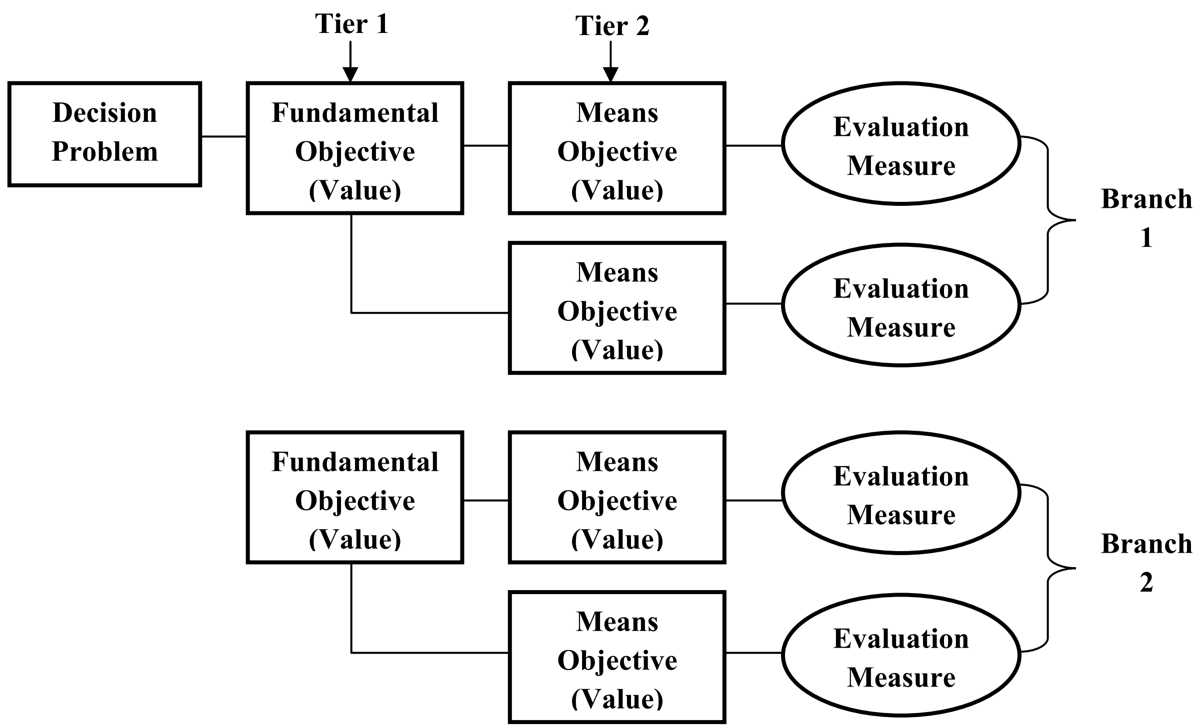


Figure 8. Generic Value Hierarchy (Adapted from Jeoun, 2005)

The third step of VFT is to develop evaluation measures to determine the degree of attainment of each objective (i.e., value); note that evaluation measures are also shown in Figure 8. There are four classifications of evaluation measures in which measures are considered natural or constructed and direct or proxy (Kirkwood, 1997). A natural-direct measure is preferred because it consists of a natural scale, or a scale that is well known and used, and directly measures the degree of attainment. The least desirable measure is a constructed-proxy measure because it consists of a scale that was constructed just for the purpose of the particular problem and does not directly measure the degree of attainment; it is only compared to a proxy for the measure. Once the measures are determined, the measurement scales need to be developed. The objectives could be

measured on a continuous scale between a minimum and maximum value or there could be categories. It is critical that each scale be well defined to ensure repeatability of the decision. Kirkwood (1997) stated that "ambiguous scales impede communications." However, there is a tradeoff that must be made between the level of effort required to develop the scales and the ease of assessing the alternatives (Kirkwood, 1997).

The fourth step is to develop the value functions so that each objective can be measured using the same units. Each evaluation measure will most likely have different units associated with it; therefore, a value function is created to put all the measures on a normalized scale from zero to one using units of value (Kirkwood, 1997). The least desirable score is given a value of zero and the best score is given a value of one; scores in between are assessed based on the shape of the value curve. Value curves can be monotonically increasing (more is better) or decreasing (less is better) and can be continuous or discrete. Discrete value functions are used for categorical measures and continuous functions can be linear, piecewise linear, or exponential (Kirkwood, 1997).

The fifth step is to assign a weight to each value to assess the degree of importance to the decision-maker (Kirkwood, 1997). However, it is often difficult for the decision-makers to decide the relative importance of the values. To say one value is three or four times more important than another can be very subjective, which is one limitation of the VFT methodology. However, this subjectivity can be partially alleviated through sensitivity analysis on the weights, to be discussed in step nine. The local weights are assessed at each level in each branch of the hierarchy and must sum to one. Then global weights can be calculated to determine each value's overall influence on the ultimate

decision; the sum of all the global weights must also sum to one. At this point, the hierarchy is complete and alternatives can be generated.

The sixth and seventh steps are alternative generation and scoring. A list of potential alternatives must be created and can include anything that could possibly be a solution to the decision problem. The decision-makers will most likely provide several known alternatives and additional alternatives can be generated through research, brainstorming, creative problem solving, or other techniques using the value hierarchy. Usually, a screening process is used to weed out alternatives that are obviously inferior. Once all alternatives are determined, they are scored against each evaluation measure. This requires data gathering and some expert judgments from the decision-makers.

After all the alternatives are scored, they are given an overall value and ranked through deterministic analysis, which is step eight. An additive value function equation is shown in the following equation (Kirkwood, 1997):

$$v(x) = \sum \lambda_i v_i(x_i) \text{ (from } i = 1 \text{ to } n\text{)} \tag{14}$$

where $v(x)$ = overall score for alternative x

λ_i = global weight for evaluation measure i

$v_i(x_i)$ = value score for alternative x from SDVF for measure i

n = total number of evaluation measures

The alternative with the highest value is then considered the most preferred alternative.

After the deterministic analysis, the ninth step is to conduct sensitivity analyses on the weights given to each value. The sensitivity analysis is initially conducted on the first-tier weights to see how changes in these weights affect the overall ranking of alternatives. If an alternative ranking is found to be highly sensitive, meaning that a

slight change in value preference causes a change in alternative ranking, the decision-maker should be alerted and review the weights to ensure confidence. The next and final step is to recommend an alternative. However, a probabilistic analysis will be necessary if there is a range of scores given for any of the alternatives.

Probabilistic Analysis

There are two different procedures to incorporate uncertainty into a VFT application: expected utility (E(U)) and certainty equivalent (CE). Both procedures result in the same ranked order of alternatives; therefore, only E(U) will be discussed within the text (CE analysis is included in Appendix F for reference). Additionally, introduction of uncertainty in the alternative scores incorporates the idea of risk into the ultimate outcome. Therefore, both procedures incorporate the decision-makers' risk behavior into the assessments. Yet, before either of the procedures can be accomplished, it is necessary to translate the continuous uncertain range of scores into a discrete approximation.

Approximation

Approximation is a way to assign discrete probabilities to a continuous range of scores. To accomplish this, the decision-maker should specify the range and distribution of the possible scores. The most accurate method to determine the expected value over the range of scores is to use a probability density function (Kirkwood, 1997). However, this requires integrating the probability distribution equation, which is often unknown and difficult for most decision-makers to calculate. Therefore, using an approximation is

generally considered adequate for most applications (Kirkwood, 1997). The approximation method used in this study is the Extended Pearson-Tukey method where the continuous quantity is transformed into a discrete quantity with three levels. The levels are set equal to the 0.05, 0.50, and 0.95 fractiles of the continuous quantity. The 0.05 and 0.95 fractiles are both assigned probabilities of 0.185 and the 0.5 fractile is assigned a probability of 0.63 (Kirkwood, 1997). Once the approximation is complete, the risk behavior of the decision-maker must be assessed.

Multi-Attribute Risk Tolerance

There are three general attitudes toward risk: risk averse (avoids risk), risk neutral (indifferent to risk), and risk seeking (Kirkwood, 1997). Expected utility calculations are useful because they allow for consideration of the decision-makers' risk behavior in determining the best alternative. The key parameter in a basic utility function is the multi-attribute risk tolerance (ρ_m). Figure 9 shows an exponential utility function graph of various ρ_m values; the range of ρ_m values shown in the figure is greater than usually exists in practice (Kirkwood, 1997). Most decision makers are risk averse with ρ_m equal to around 0.2. Any value of ρ_m greater than or equal to 10 or less than -10 is essentially a straight line indicating risk neutrality (Kirkwood, 1997).

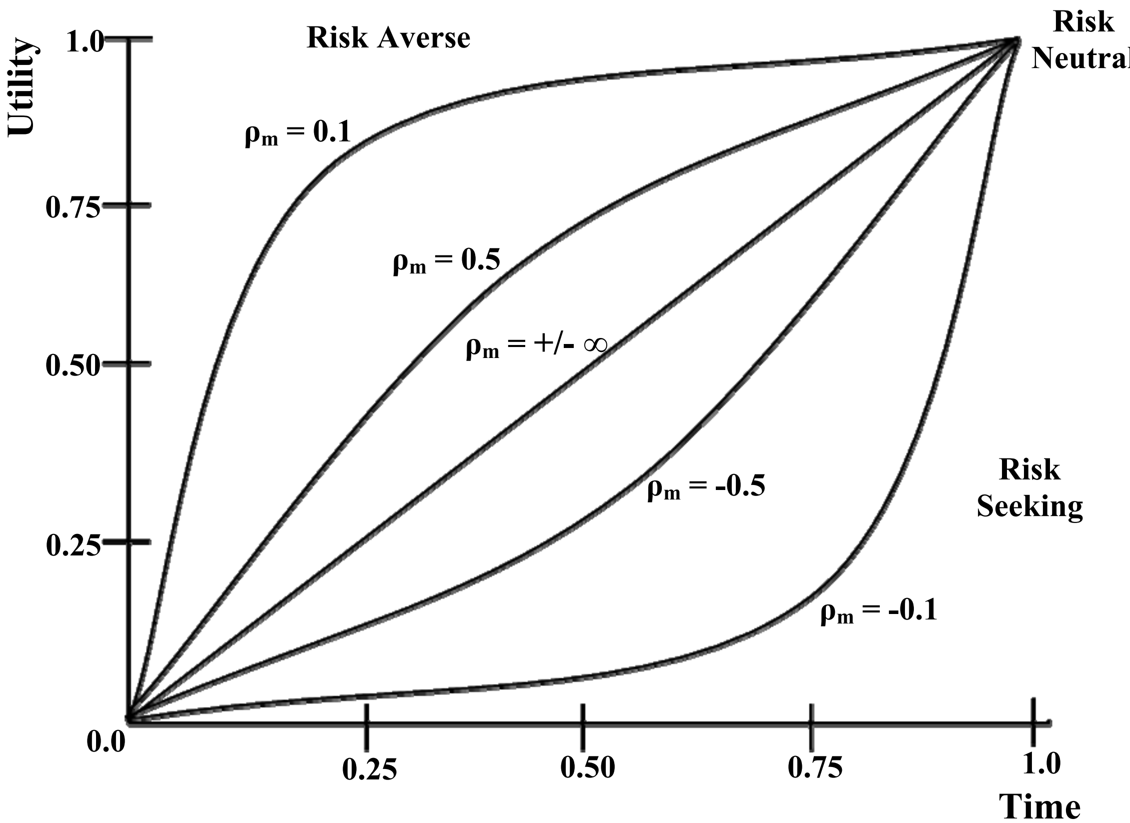


Figure 9. Exponential Utility Functions (Adapted from Kirkwood, 1997)

One common method to calculate ρ_m is to construct a lottery (as shown in Figure 10) in which the decision-maker is given a 50/50 chance of the best case or worst case scenario and asked to define a certain hypothetical alternative that would make him or her indifferent to playing the lottery (Clemen & Reilly, 2001). The value of the hypothetical alternative is calculated through use of the additive value function and ρ_m is determined through the following equation (Kirkwood, 1997):

$$0.5 = (1-\exp(-z_{0.5}/\rho_m)) / (1-\exp(-1/\rho_m)) \qquad (15)$$

where $z_{0.5}$ = value of the hypothetical alternative

ρ_m= multi attribute risk tolerance

The values for ρ_m typically range from -0.5 (risk seeking) to 0.5 (risk averse). Most decision-makers (especially those making decisions with public funds) are risk averse with a $\rho_m = 0.2$ (Kirkwood, 1997).

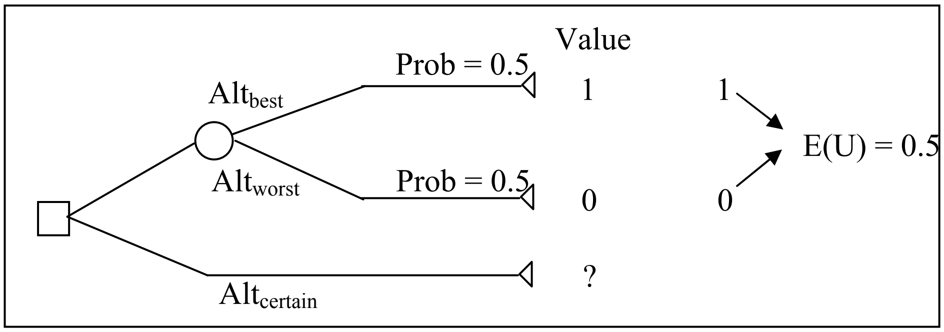


Figure 10. Alternative Lottery

Expected Utility

After determining ρ_m, the expected utility for each alternative can now be found. First, all possible outcomes must be considered for each alternative. This can be a cumbersome process if there is more than one evaluation measure with uncertainty. For example, if an alternative has three possible scores for three different evaluation measures, there would be 27 possible outcomes (3^3). Next, the value of each outcome is calculated using the following equation (adapted from Kirkwood, 1997):

$$V_{ji} = \sum (W_{jik}) (V_{jik}) \qquad (16)$$

where V_{ji} = Value of alternative j for outcome i

W_{jik} = Weight of alternative j for outcome i for evaluation measure k

V_{jik} = Value for alternative j for outcome i for evaluation measure k

Outcome values are then transformed and recorded into outcome utilities using the following equation (adapted from Kirkwood, 1997):

$$U_{ji} = (1-e^{(-Vji/\rho m)}) / (1-e^{(-1/\rho m)}) \tag{17}$$

where U_{ji} = Utility of alternative j for outcome i

V_{ji} = value of alternative j for outcome i

ρ_m = multi-attribute risk tolerance

Lastly, the expected utility is calculated for each alternative using the sum product of each alternative's outcome probabilities and outcome values using the following power additive utility function (adapted from Kirkwood, 1997):

$$E(U_j) = \sum (P_{ji}) (U_{ji}) \tag{18}$$

where $E(U_j)$ = expected utility of alternative j

P_{ji} = probability of alternative j for outcome i

U_{ji} = utility of alternative j for outcome i

Once the expected utilities are calculated for each alternative, the alternatives are ranked accordingly.

Summary

This chapter presented a summary of the available literature on the causes and effects of deferred maintenance, research on recapitalization estimation models and techniques, and the DoD models currently in use and proposed for future use. Additionally, the VFT decision analysis process was described which included deterministic and probabilistic analyses. The results of the literature review reveal the answers to the first three research questions.

III. Methodology

This chapter addresses the fourth research question: "What values are important to the DoD decision-makers for selection of the best recapitalization method?" It details the specifics of the first six steps of the Value Focused Thinking (VFT) process: identify the problem, create value hierarchy, develop evaluation measures, create single dimensional value functions, weight value hierarchy, and generate alternatives (Shoviak, 2001). The result of these six steps is the creation of a value model, which will then be used for analysis in Chapter IV. The model will serve as a decision tool for Department of Defense (DoD) decision-makers to aid in the selection of the best budget method for recapitalizing DoD facilities.

Step 1 – Identify the Problem

As a result of various Government Accounting Office (GAO) reports that found the DoD was not managing its facilities properly, DoD program managers initiated changes to their facility management practices (GAO, 1997, 1999, & 2000). The first major change was to implement the Facilities Sustainment Model (FSM) to help predict and manage sustainment budget estimates (DoD, 2006). The model used a percentage of the Plant Replacement Value (PRV) as its budget estimate. This model was widely accepted by all the services, and Congress routinely funded about 95% of the model output value. The vast amount of success with the FSM led DoD decision-makers to attempt to create a model for recapitalization, which was a more difficult task than sustainment because of different funding classifications and funding sources. DoD

program managers eventually created the Facilities Recapitalization Model (FRM) which was similar to the FSM; it also used the PRV as a ratio in combination with the expected service life of facilities, which averaged out to 67 years (DoD, 2002). However, the concept of recapitalization and the 67-year life span was hard for decision-makers to comprehend. This led to difficulties in convincing the leadership to support the FRM and prompted the Installations Review Panel to develop the new Facilities Modernization Model (FMM), which changes the recapitalization metric from a 67-year life span to a percentage of the model result, just like the FSM model. The FMM is expected to be implemented in the year 2010; however, it is not without flaws.

The research problem and subject of this thesis, as stated in Chapter I, is that asset managers are expected to justify the costs of facility recapitalization requirements against other competing requirements; however, there is a lack of research that compares recapitalization models and evaluates which method is best suited for a particular organization. The problem, as restated for development of the value hierarchy is: "What is the best recapitalization budget estimation method for the DoD?" Although the ultimate decision-maker regarding which model to use is the Under Secretary of Defense for Installations and the Environment, the decision-makers used for this VFT analysis consisted of a panel of recapitalization program managers who are subject matter experts from the DoD, Air Force, Army, Navy, and Marines. The panel members are not only experts, but they also have access to the decision maker and are aware of his preferences and policies with regard to the recapitalization program. Due to the large number of panel members, the DoD program manager had ultimate decision authority if any

conflicts of opinion were encountered. Once the problem was identified and the decision panel selected, the value hierarchy was created.

Step 2 – Create the Value Hierarchy

When creating the value hierarchy, it was necessary to sit down with the decision-maker panel to brainstorm the values important to them and the characteristics of a successful recapitalization program. The techniques listed and described in Table 5 were used to solicit the values of the decision-makers (DMs). The first six techniques were used to discover values by asking questions to find out what matters to the DMs. The last four techniques were used to structure the values into a hierarchy; during this process, some additional values were discovered.

Table 5. Techniques for Creating a Value Hierarchy (adapted from Keeney, 1992)

TECHNIQUE TO SOLICIT VALUES	DESCRIPTION
1. A wish list	Asking decision-makers (DMs) what their objectives would be if there were no limitations
2. Alternatives	Asking the DMs what makes one alternative better than another or what makes a perfect alternative and why
3. Problems and shortcomings	Asking about what the problem is with the current methods and what needs to be changed
4. Consequences	Asking if there were certain consequences that would be unacceptable
5. Goals, constraints, and guidelines	Asking if there are specific standards to be met or other guidelines
6. Different perspectives	Asking the DMs to think about the problem from the perspective of stakeholders at different levels
7. Strategic objectives	Asking how alternatives contribute to the fundamental objectives for all situations
8. Generic objectives	Provides a basis for developing specific objectives in a given decision situation
9. Structuring objectives	Separating means from fundamental objectives and establishing the hierarchy
10. Quantifying objectives	Ways to measure the degree of attainment of the means objectives

After going though the hierarchy building process with the DMs, the value hierarchy was established. During this brainstorming process, the panel decided that there were three main categories of objectives (or values): *Prevent Obsolescence, Credible Model,* and *Implementation*. This section will describe the first-tier objectives and their associated lower tier objectives to help provide an understanding of their importance to the decision panel.

The first objective, *Prevent Obsolescence*, is the general goal of any recapitalization program. This objective was broken down further into three second-tier

objectives as shown in Figure 11. The first second-tier objective was *Predictive Capability*, which refers to the ability of the model to predict future requirements. The next second-tier objective was *Meets Industry Standards*, which was further broken down into three third-tier objectives: *Condition Assessment Method, Life-Cycle Method*, and *Empirical Results*. There are no specific standards used in practice, but the literature review revealed empirical support of condition assessments and life-cycle methods in addition to other specific models. The decision panel also found value in models that had support in published research which is reflected in the binary value *Empirical Results*. The last second-tier objective under *Prevent Obsolescence* is *Sensitivity to Investment Behavior*. Investment behavior refers to the historical trend of funds spent on recapitalization projects and whether the organization typically recapitalized through renovation, replacement, or a combination. The decision-makers desired a model that included the typical investment behavior into the model output value.

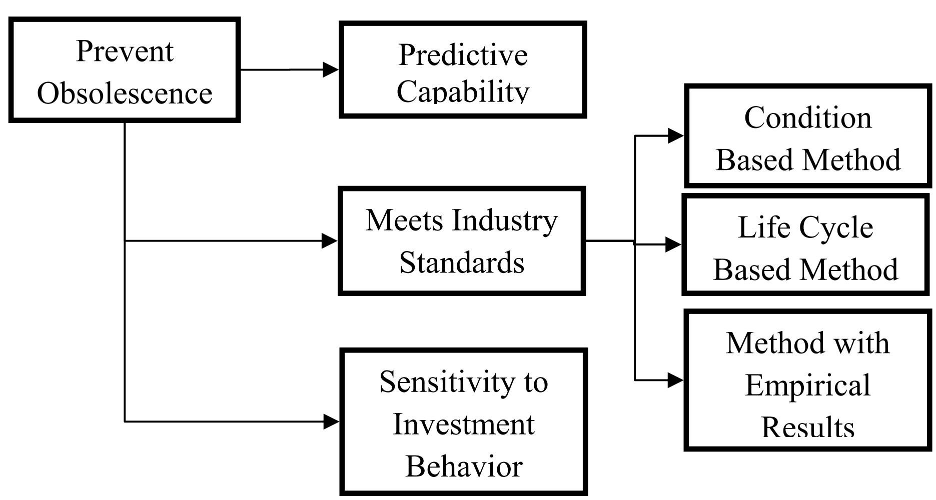


Figure 11. Breakdown of First-Tier Objective (*Prevent Obsolescence*)

The next first-tier objective, *Credible Model*, refers to the credibility of the model from the perspective of the program managers and the upper leadership who provides the funding; for this research, these leaders are the Under Secretary of Defense for Installations and the Environment and members of Congress. The breakdown of this objective is shown in Figure 12 and describes the aspects that help the leadership to comprehend and support the model. The first second-tier objective for *Credible Model* is *Understandable*, which refers to the ability of leaders to understand the model and its output. The next second-tier objective is *Integrity of Inputs*, which is further broken down into the third-tier objectives of *Facility Type Life-Cycles* and *Use of Facility Factors*. The decision panel found value in breaking down facilities into facility types because each type of facility is used differently and constructed for various life-cycles; they brainstormed the types of factors they valued and categorized them into three types: A, B, and C (which refers to the level support and confidence the panel members have in the factor). The last second-tier objective is *Consistency of Budget Requests*, which means that the panel found value in a model that would produce consistent estimates from year to year. Based on the previous experience of the panel members, decision-makers were often flustered and confused when budget requests varied widely from previous requests.

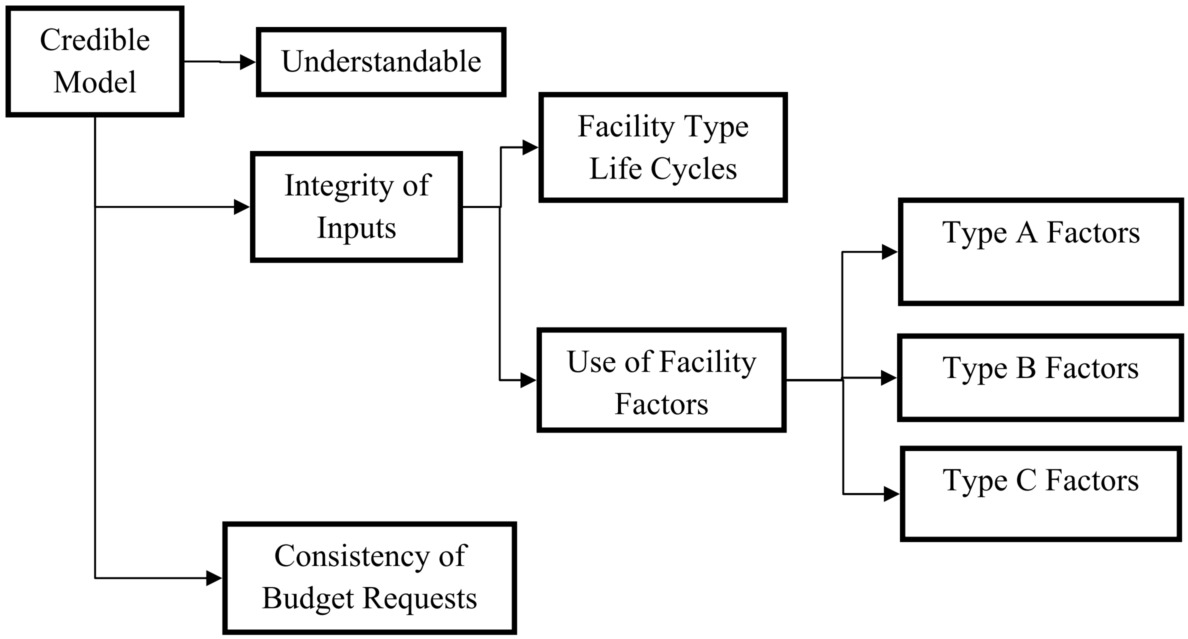


Figure 12. Breakdown of First-Tier Objective (*Credible Model*)

The final first tier objective, *Implementation*, refers to the estimated amount of effort involved in implementing an alternative. There could be both cost and time aspects to *Implementation*; however, the panel decided to only look at the time aspect from the perspective of the DoD program mangers, the service program managers, and the Major Command (MAJCOM) and base personnel. Cost was omitted from the hierarchy because the panel decided that it was not feasible to accurately estimate the implementation costs of the models. Additionally, the panel did not want to cause extra work for the personnel involved in the implementation of the models, especially those at the MAJCOM and base levels. The breakdown of *Implementation* is shown in Figure 13.

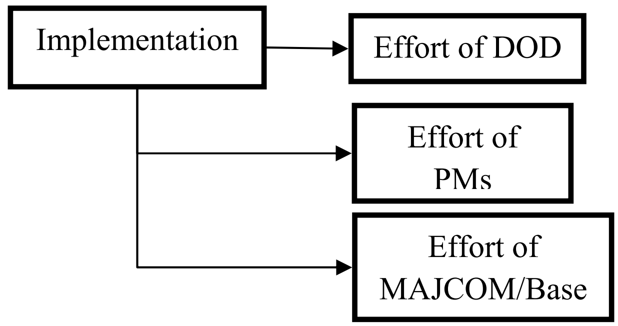


Figure 13. Breakdown of First-Tier Objective (*Implementation*)

Step 3 – Develop Evaluation Measures

Developing evaluation measures involves establishing the most accurate and feasible ways of quantifying the lowest tier objectives. Evaluation measures are what transform subjective values into an objective measurable format to measure attainment. Like the process for establishing values, evaluation measures for this problem were created by the decision panel of experts. Keeping in mind from Chapter II that evaluation measures must be measurable, operable, and understandable, the decision panel developed measures for each of the lowest tier values. The evaluation measure definitions are located in Appendix A. Figure 14 shows an updated version of the value hierarchy with the evaluation measures included.

Step 4 – Create Value Functions

The next step was to define value functions for each of the evaluation measures. As stated in Chapter II, value functions are used to convert measures to the same scale so that corresponding values vary from zero (least preferred score) to one (most preferred score) over the range of possible scores on a measure. To define the Single Dimensional Value Functions (SDVFs), one must define the range of values and then decide the shape of the value function. Only categorical, continuously increasing (linear and piecewise), and continuously decreasing (linear) value functions were used for this research. Examples of each kind of SDVF used in this analysis are described in this section; a summary of all evaluation measures and their corresponding SDVFs are located in Appendix B.

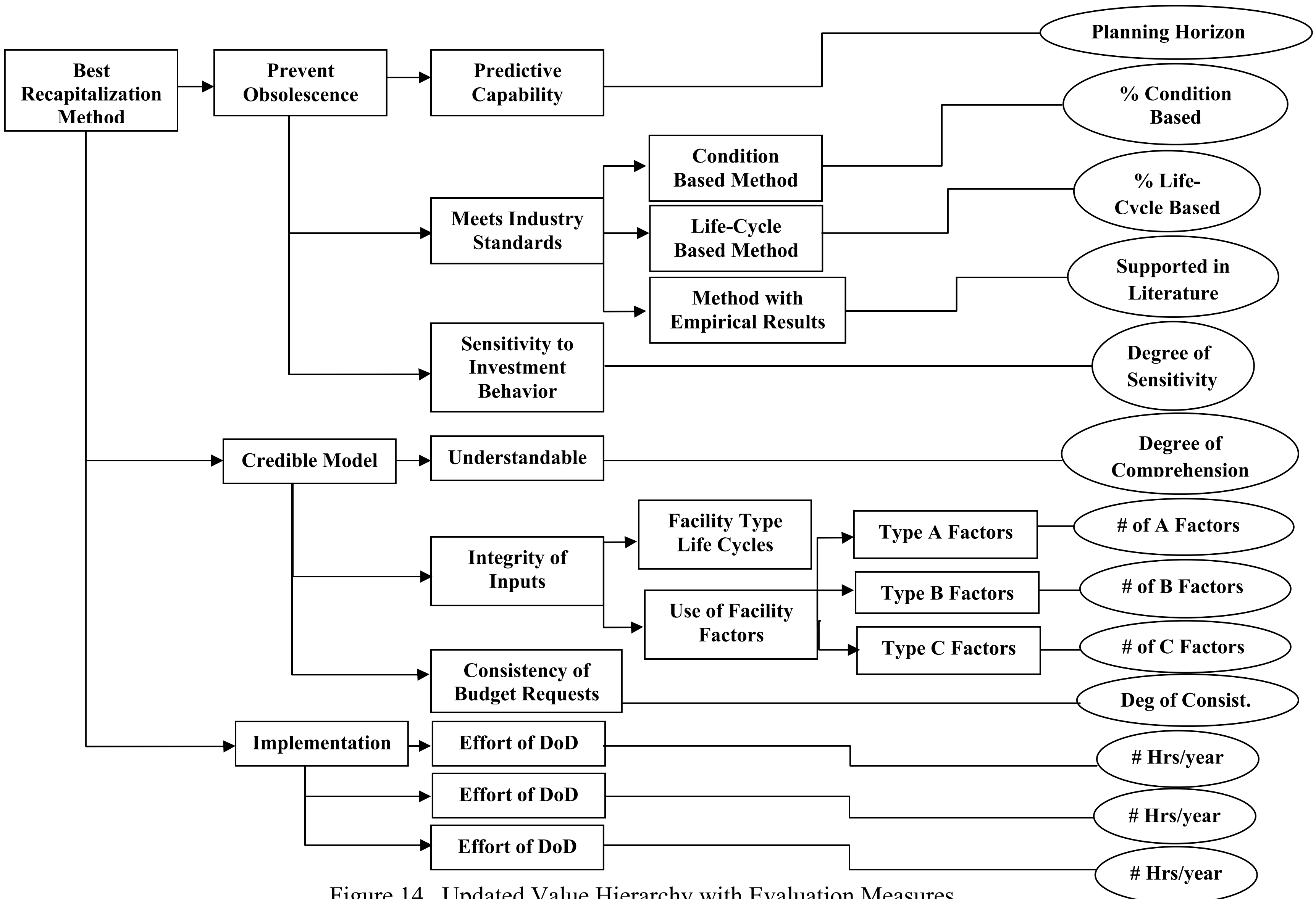


Figure 14. Updated Value Hierarchy with Evaluation Measures

In this thesis, the SDVFs were defined during group discussion in which consensus was reached among the decision panel members. First, the panel assigned a range of possible scores for each measure. Next, the panel decided how the value function changed throughout the range of scores. If piecewise linear or categorical measures were used, the panel used value increments to determine the shape of the respective SDVFs.

A piecewise linear SDVF was only used for one evaluation measure in this hierarchy, *Predictive Capability.* This evaluation measure will be used to illustrate the procedure to establish a piecewise linear SDVF. First, the measure was given a range from 0 to 30 years. Since this measure was continuous, the panel had to decide whether the function would be straight-line, piecewise linear, or exponential. To make this decision, the panel members examined whether each increase in score should receive an equal amount of increase in value. Otherwise stated, a straight-line SDVF would indicate that the increase from 0 to 5 years (increase in value of 0.167) would be the same as the increase from 5 to 10 years (an additional 0.167 for a total of 0.33). However, the panel members found that there were natural divisions in the planning horizon in which some intervals had more value than others. These divisions were 3, 5, 10, and 30 years. Consequently, value incrementing was used to determine the value associated with each of the intervals. The first step in value incrementing is to decide the least important score increase and assign it a score of K. The next step is to determine the next least important score increase and decide how much more valuable it is than the previous interval; this process is repeated until all intervals are assigned a value. For *Predictive Capability*, the

value increment results are summarized in Table 6. The resulting value function in graphical form is shown in Figure 15.

Table 6. Value Increments for *Predictive Capability* SDVF

Interval	**Value Increment**	**Value of Increment**	**Value in Decimal**	**Score**	**Value of Score**
10 – 30 yrs	K	1/12	0.083	30 yrs	1
5 – 10 yrs	2K	2/12	0.167	10 yrs	.917
3 – 5 yrs	3K	3/12	0.25	5 yrs	.75
0 – 3 yrs	6K	6/12	0.5	3 yrs	.5
Total	12 K	1	1		

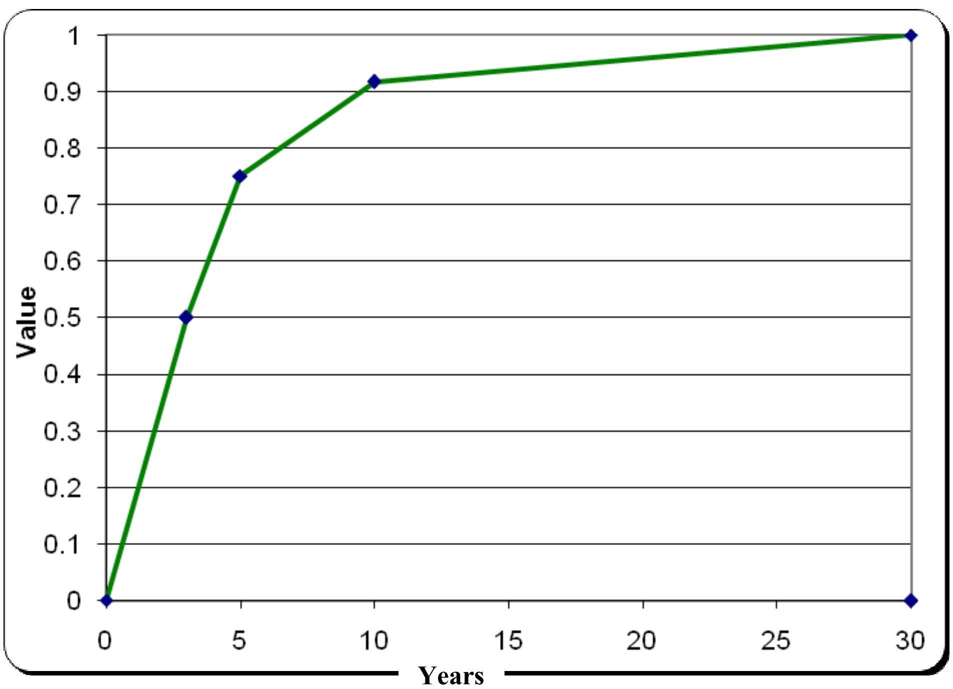


Figure 15. *Planning Horizon* SDVF

Another type of SDVF used in this analysis is the straight-line function, which is another continuous measure. The continuously increasing straight-line function is used for six of the measures and the continuously decreasing straight-line function is used for three measures. Continuously increasing refers to the case where a higher score is better, such as the evaluation measure for *Condition Assessment Method*. Continuously decreasing is the opposite where less is better, such as the evaluation measures used for *Implementation*. Figure 16 shows a graphical SDVF example for *Condition Based Method* (increasing) and Figure 17 shows the SDVF for *Effort of DoD* (decreasing).

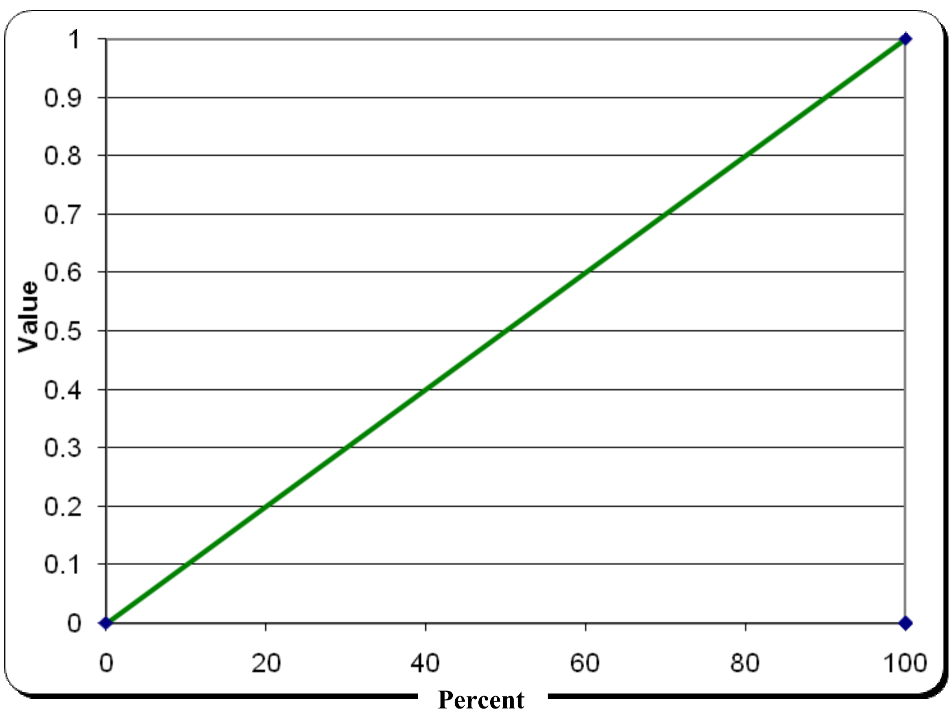


Figure 16. Continuously Increasing Linear SDVF for *Condition Based Method*

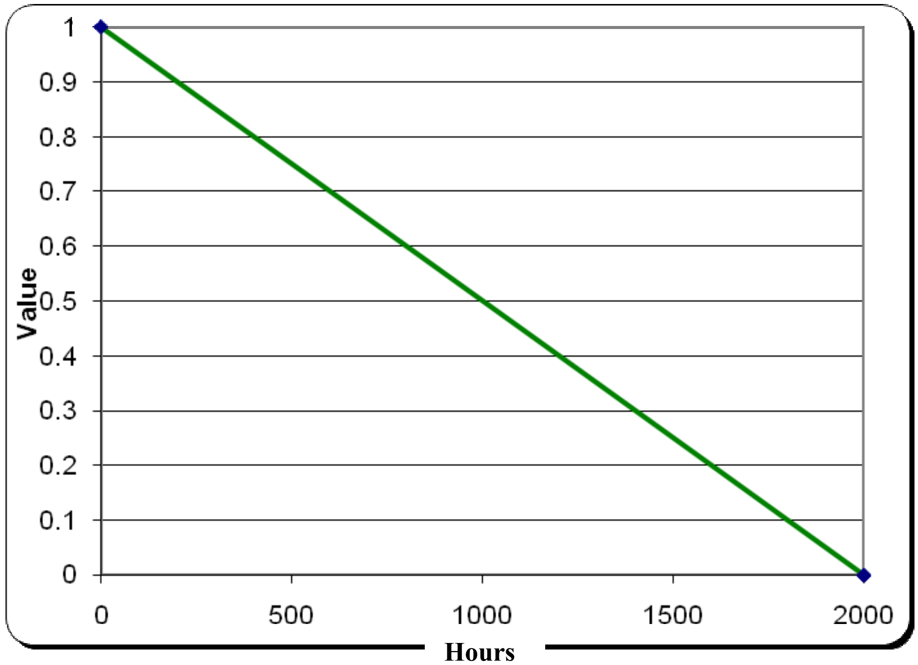


Figure 17. Continuously Decreasing SDVF for *Effort of DoD*

The last type of SDVF used in this research was a discrete categorical measure. Value incrementing was also used to assign values to the increase in intervals for these measures. *Sensitivity to Investment Behavior* is an example of a categorical measure. The lowest level is given a score of zero and the highest is given a score of one. Each categorical measure had three or less categories so using value increments was relatively simple. For *Sensitivity to Investment Behavior*, the panel decided that the interval from Low to Medium (value of .67) was twice as important as the interval from Medium to High (value of .33). The resulting SDVF is shown in Figure 18.

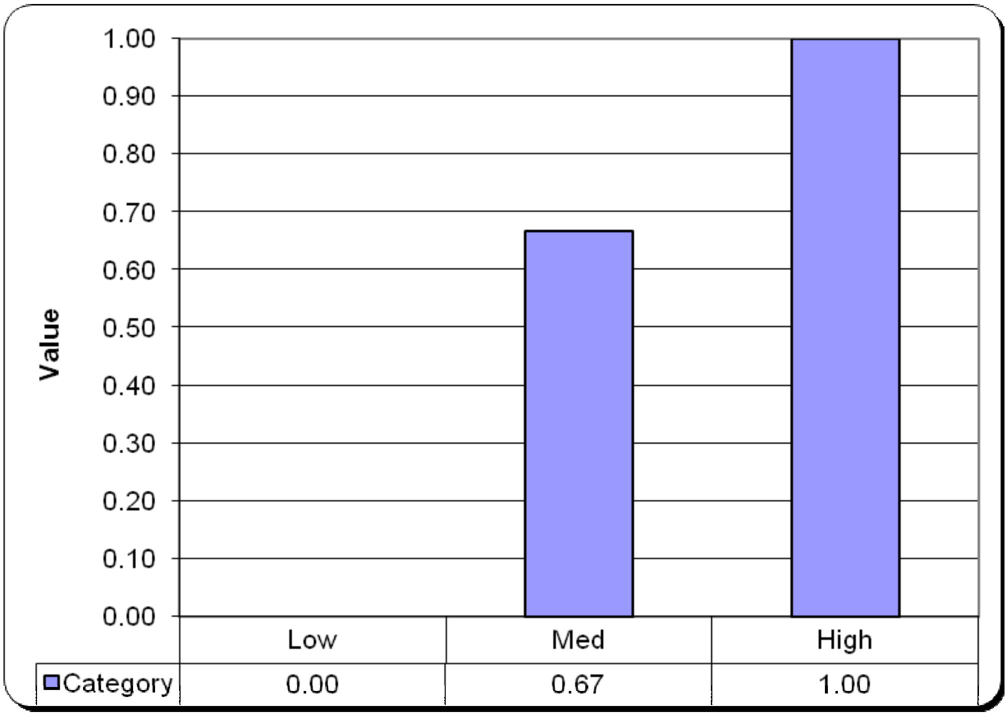


Figure 18. SDVF of *Sensitivity to Investment Behavior*

Step 5 – Weight the Value Hierarchy

Weighting is the final step necessary to complete the value hierarchy. The local weights were found by examining each tier of each branch and the relative importance of the applicable values. For example, in the first tier of the hierarchy, *Implementation* was considered the least important value and was given a score of K. The decision-makers were then asked to identify the next least important value and state how much more important it was than the previous value. The decision-makers decided that *Prevent Obsolescence* was three times as important as *Implementation*, so it was given a score of 3K. The last value was given a score of 5K, because it was considered five times more

important than *Implementation*. Therefore, the total of all the scores was equal to 9K, and each K equaled 1/9. This was done for each tier of each branch of the hierarchy, and the completed hierarchy is shown in Figure 19. The global weights are also shown in Figure 19. The global weights of all lowest tier values must sum to 1.0 and are the weights that are the most important for analysis purposes because they denote the overall importance that each evaluation measure contributes to the overall alternative score.

The three second-tier values under *Implementation* were weighted as shown in Figure 19 because of the number of employees that typically perform the recapitalization work at each level in the hierarchy. For example, most bases have only one person performing recapitalization estimation work, but there are many bases across the DoD; this explains the higher weight of *Effort of MAJCOMS/Bases*. Therefore, any effort required of base workers effects hundreds of individuals, whereas the effort required of PMs affects only a few individuals. The decision panel assigned the weights according to their preferences of distribution of work load for the recapitalization program.

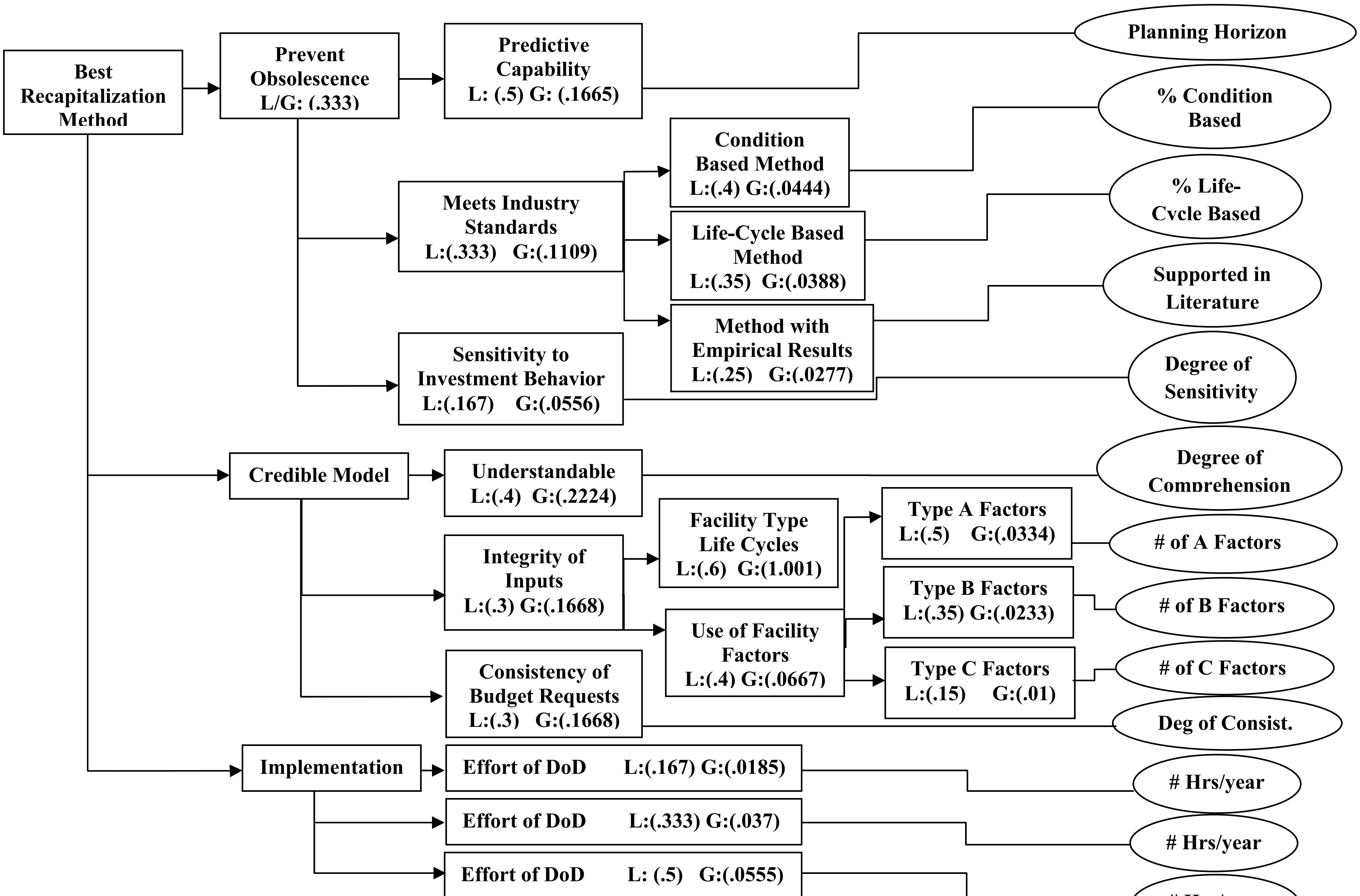


Figure 19. Completed Value Hierarchy

Step 6 - Alternative Generation

Many potential alternatives for DoD recapitalization were found through the literature review and were listed in Table 3 in Chapter II. After the hierarchy was established, the decision-makers thought about other possible alternatives that could be considered. They thought about modifications that could be made to improve existing models, allowing them to score better according to the value model. The decision-makers also thought about past methods of recapitalization estimation and existing practices that could be used as an estimation model. The alternatives that the decision-makers decided to include were the bottom-up method, Q-Rating system, a variation of FRM with updated facility service lives (Alt FRM), and a variation of FMM with accelerated depreciation pattern (Alt FMM). The bottom-up method would be the "do nothing" option because it involves eliminating the budget model program altogether and relying only on the funding requests submitted by the bases and MAJCOMs. The Q-rating system would take the facility rating system currently in place and use that as the basis for funding. The updated FRM method would incorporate the research on facility life cycles instead of using an average facility life as it does now. The variation of the FMM model consists of altering the depreciation pattern from straight-line to a pattern that has empirical support for each type of facility considered.

In addition to the alternatives described in Chapter II and those described above, a hypothetical alternative called the H-Model was created by the decision panel in an attempt to maximize the possible value from the hierarchy that is within the realm of feasibility. This was created to test the value model to determine if an original alternative could be created that would result in a higher value than any existing alternative. This

alternative, as well as all the other alternatives, are listed in Table 7; they are also summarized and defined in Appendix C.

Table 7. Alternative Table

MODEL	Formula Based	Estimating Approach Condition Assessment	Life-Cycle
CPV	X		
PRV	X		
Dergis-Sherman	X		
Facilities Renewal	X		
Depreciation	X		
BUILDER		X	X
Renewal Factors			X
AME		X	
FRM	X		
FMM	X		
Bottom-Up			
Q-Rating System		X	
Alt FRM	X		
Alt FMM	X		
H-Model		X	

Summary

This chapter presented the specifics of the first six steps of the VFT process, including: defining the problem, developing the value hierarchy, creating the evaluation measures and value functions, weighting the hierarchy, and generating the alternatives. In Chapter IV, the last four steps will be completed including the deterministic and probabilistic analyses. The final chapter will discuss the results and any modifications made to the model.

IV. Results and Analysis

This chapter contains the results and analysis of the value model. Included in the analysis are details of the next few steps in the Value Focused Thinking (VFT) process: Step 7- alternative scoring, Step 8- deterministic analysis, and Step 9 - sensitivity analysis (Shoviak, 2001). As a result of the alternative scoring, the deterministic analysis will provide a rank ordering of alternatives. The sensitivity analysis will analyze how the weights of the various values impact the alternative rankings. This section will also include a probabilistic analysis or assessment of uncertainty, which includes an assessment of the risk tolerance of the decision-makers to find the expected utility of the alternatives. As a result of this section, the fifth and sixth research questions will be answered: what method should Department of Defense (DoD) decision-makers use for facility recapitalization budget estimation and what are the decision-makers' risk preferences with regard to recapitalization models?

Step 7 – Alternative Scoring

After all the alternatives were determined, they were individually scored according to their level of attainment of each evaluation measure. To accomplish the scoring, data had to be collected on each of the alternatives. Most of the data used for scoring came from the subject matter experts who have the experience to know or estimate the scores for each alternative. However, some of the scores were based on empirical evidence gained from literature. For example, to determine which facility factors were used for some of the alternatives, the journal articles for the models were

used. For *Degree of Consistency* though, the opinion of the decision-makers was used for an estimation of the consistency of the budget requests. Appendix C contains the alternative scoring sheets along with the source of each score.

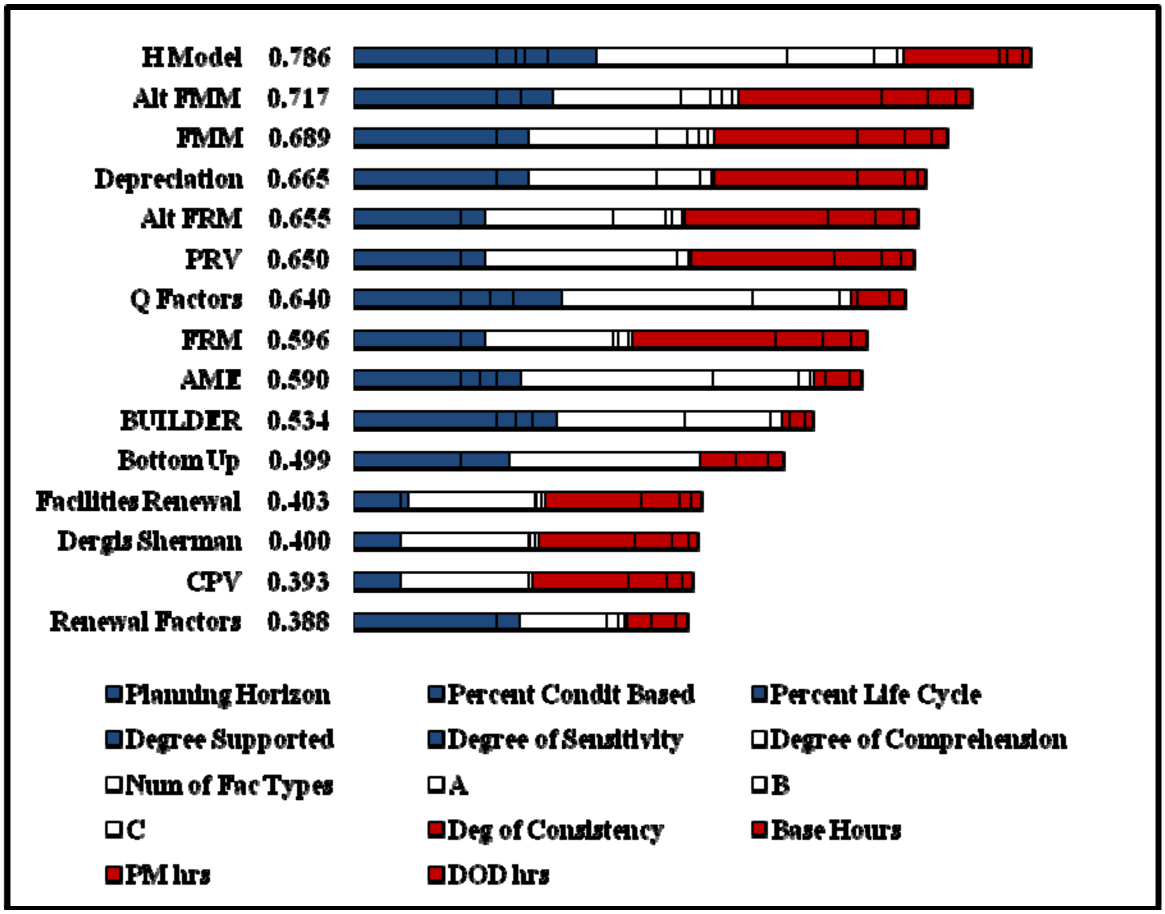
The evaluation measures and alternatives should be defined clearly so that anyone with knowledge of recapitalization models would independently score the alternatives the same. Therefore, two members of the decision panel were asked to individually score the alternatives to ensure that consistency and repeatability was achieved. The panel members were given a score sheet for each alternative that contained guidance on scoring for each evaluation measure and descriptions of the alternatives. If the literature was the source of the score, then the score was already listed on the score sheet. Initially, the results varied more than expected in several areas. Therefore, as a compromise, the panel members worked together on the discrepancies and either agreed upon a score or agreed to a specified range of possible scores to be evaluated in the probabilistic analysis. The decision panel members decided to provide a range of scores on the *Implementation* evaluation measures for each alternative because there was some uncertainty in the number of hours required to implement each model. The final score sheets and summary table of the raw scores are shown in Appendix C and Appendix D, respectively.

Step 8 – Deterministic Analysis

Deterministic, by definition, does not contain uncertainty. Therefore, for the purposes of the analysis in Step 8, the mid-range value was used for any alternative that had a range of values within an evaluation measure. The score data was entered into the *Hierarchy Builder* macro for Microsoft Excel, written by Weir (2007), that performed the

analysis using additive value functions. The value scores and expected value scores were also calculated in a spreadsheet to ensure accuracy (see Appendix D). The additive value function converts the raw score data into values using the SDVFs and takes a weighted sum to determine the overall value of each alternative. The results are shown in Figure 20 in a bar graph format with each alternative listed in ranked order on the left followed by its overall numerical value. The bars are shaded to depict the portion that each first-tier value contributed to the overall value of that alternative. For example, the longest bar in the H-Model corresponds to *Credible Model*. This means that the *Credible Model* value contributed the largest portion to the overall value of the H-Model. The overall value score of the H-model is 0.786, which means that even the best alternative can only meet about 79% of the decision-makers' values.

The results of the deterministic analysis are also presented in Figure 21, which shows how each bottom tier value contributed to the overall value of the alternative. Each evaluation measure has a specific color (as shown in the key) and length to denote the portion of the alternative's value that came from each measure. For example, the measure that contributed most to the value of the H-Model is degree of comprehension.



LEGEND OF FIRST-TIER VALUES	
	Prevent Obsolescence
	Credible Model
	Implementation

Figure 20. Ranked Alternatives by First-Tier Values

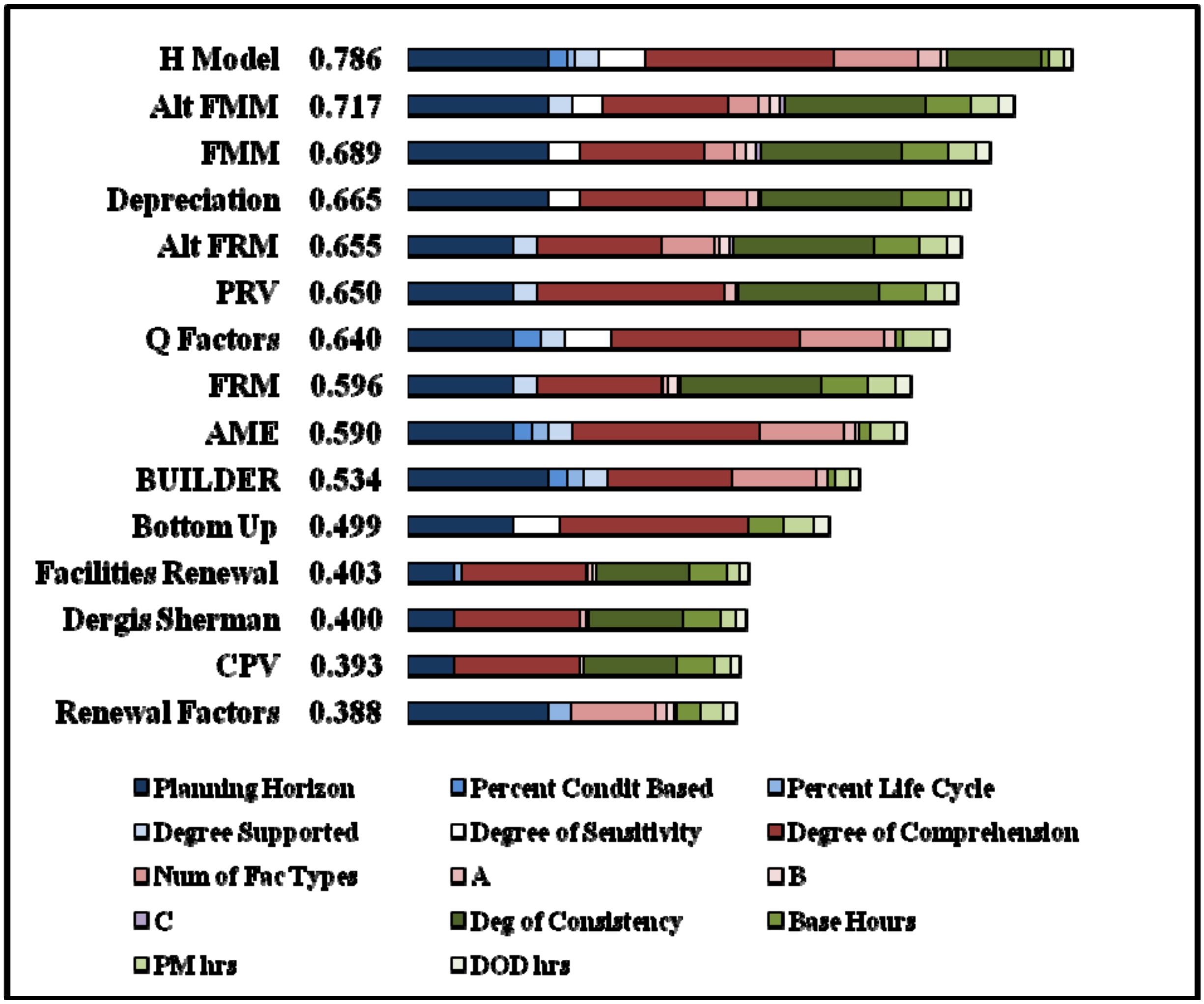


Figure 21. Ranked Alternatives by Evaluation Measures

Several areas of insight can be gained through the deterministic analysis. First off, the decision-makers can clearly see the ranked order of the alternatives: the H-Model scored the highest in value, closely followed by the Alternate FMM and then FMM. Additionally, when separated by type of model (formula, condition, or life-cycle), there is

no clear type that dominates over the others. The models in the three various categories are mixed among the ranks with the top scorer being a mix of formula and condition, followed by several formula models and then another condition and life-cycle based model. However, the only pure life-cycle based model scored very low. This is summarized in Table 8, which is the alternative table from Chapter III with the alternatives rearranged in rank order with the type of models depicted.

Table 8. Alternatives in Rank Order by Type

MODEL	Formula Based	Estimating Method Condition Assessment	Life-Cycle
H-Model	X	X	X
Alt FMM	X		
FMM	X		
Depreciation	X		
Alt FRM	X		
PRV	X		
Q Factors		X	
FRM	X		
AME		X	
BUILDER		X	X
Do Nothing (Bottom Up Only)			
Facilities Renewal	X		
Dergis-Sherman	X		
CPV	X		
Renewal Factors			X

Another insight from the deterministic analysis is the visual image of the weights (shown in Figure 21) as specified by the decision-makers. The evaluation measures of *Planning Horizon, Degree of Comprehension*, and *Degree of Consistency* have the most

impact on the overall scores of the alternatives, as seen by the length of the bars. This is because they carry the highest global weights of all the other measures. Viewed another way, *Degree of Comprehension* and *Degree of Consistency* are within the branch for the first-tier value of *Credible Model*, which has the highest local weight of all first-tier values. An additional insight gained from the analysis is that the ranked alternatives and the length of the colored bars allow the decision-makers to see why one alternative scores better or worse than another. The length of each bar depends greatly on both the alternative's score (which for the most part is fixed) and the weight of the lowest tier value. For example, when comparing the H-Model to the Alt FMM, one can see that the length of *Degree of Comprehension* and *Facility Types* are longer in the H-model and are most likely the reasons that the H-Model has a higher value. If the decision-makers were to change the weights on those two values, the alternative ranking might change. To determine how sensitive the results are to the specified weights, sensitivity analysis is performed in Step 9. The probabilistic analysis that follows the sensitivity analysis will examine how the range of scores on certain evaluation measures impacts the results.

Step 9 – Sensitivity Analysis

By performing sensitivity analysis, the decision-makers can gain insight into how changes in a single weight can impact the overall ranking of alternatives. Ultimately, this step allows decision-makers to gain confidence in the ranked order of results. Oftentimes, sensitivity analysis can negate the need for decision-makers to come to agreement about the specific weights of the values; if the outcome does not change over a particular range of weights then the decision-makers do not need to agree to an exact weight.

Additionally, a sensitivity analysis is useful if the individual or group of individuals building the model is not the actual decision-maker, as is the case for this research problem (Jeoun, 2005). The software performs the sensitivity analysis by varying the weight of an indicated value from 0.0 to 1.0 while keeping the ratio of the other values intact. This ensures that the sum off the global weights will always equal 1.0. A decision is sensitive if the preferred alternative or ranking of alternatives changes within a reasonable fluctuation of a value's weight. If the decision is sensitive to the value's weight, the decision-makers should initially confirm they are confident in the weights as specified and alter if necessary; alternatively, they could perform additional research to ensure that the scores are accurate. The following sections discuss the sensitivity of the decision to the weights of the first-tier values and any additional sensitivity analyses as needed. If the decision is not sensitive to the first-tier value, then it will also not be sensitive to the weights of the lower tier values.

Sensitivity Analysis for *Prevent Obsolescence*

Figure 22 shows the sensitivity graph associated with *Prevent Obsolescence*. The vertical black line indicates the given weight of *Prevent Obsolescence* (0.333). Where the vertical line intersects with the top most alternative line is the most preferred alternative at that particular weight. Because the H-Model is the best alternative, this line will always be the top most alternative line at the given weight in any sensitivity chart. To determine the level of sensitivity, imagine sliding the vertical black line to the left and right. If any of the alternative lines intersect so that the topmost line changes then there is a potential sensitivity of that particular weight. The new ranking of alternatives can be

determined at any point by looking at where the alternative lines intersect the vertical line.

Prevent Obsolescence is not sensitive to the most preferred alternative; no matter what the specified weight, the H-Model will always be the most preferred. However, ignoring the H-Model, the ranking of the other alternatives are sensitive to the weight of *Prevent Obsolescence*. If the weight of *Prevent Obsolescence* changes to approximately 0.1 (an approximately 70% decrease in weight preference), the second most preferred alternative would change from Alt FMM to Alt FRM. Likewise, increasing the weight preference to about 0.75; the preferred alternative would change from Alt FMM to Q Factors. The least preferred alternative is highly sensitive at the given weight and looks like a close tie between Renewal Factors, Dergis-Sherman, CPV, and Facilities Renewal.

Some additional insight can be gained from the slope of the lines in sensitivity graphs. Alternative lines that have a positive slope indicate that the alternative becomes more preferred (its overall value increases) as the weight of the value being analyzed moves from 0.0 to 1.0. Looking at each alternative individually, an alternative with a positive slope in the *Prevent Obsolescence* sensitivity graph means that, compared to the other values in the hierarchy, that alternative performs well for this particular value. An alternative line with a neutral (horizontal) slope indicates that its overall value remains the same no matter what weight is placed on the value being analyzed. In Figure 22, the alternative lines with positive or neutral slopes are H-Model, Q-Factor, AME, BUILDER, Bottom-Up, and Renewal Factors. These six alternatives have two things in common: (1) they are the only alternatives that have either large scores for condition assessment method, life-cycle method, or combination of the two, or high scores for sensitivity and

(2) a comparatively small portion of their overall value comes from the *Implementation* measures. This second similarity is important because it shows that the negative sloping alternative lines receive most of their overall value from the other two first-tier values. Note that the FRM and FMM alternatives (the models currently being used by the DoD) and their alternate versions have negative slopes, which means that the overall value of these alternatives decrease as *Prevent Obsolescence* becomes more important. This shows that other alternatives exist that prevent obsolescence better than the models currently in use. This indicates that if the decision-makers can further modify these models to improve their ability to prevent obsolescence then their overall performance would improve according to their value model.

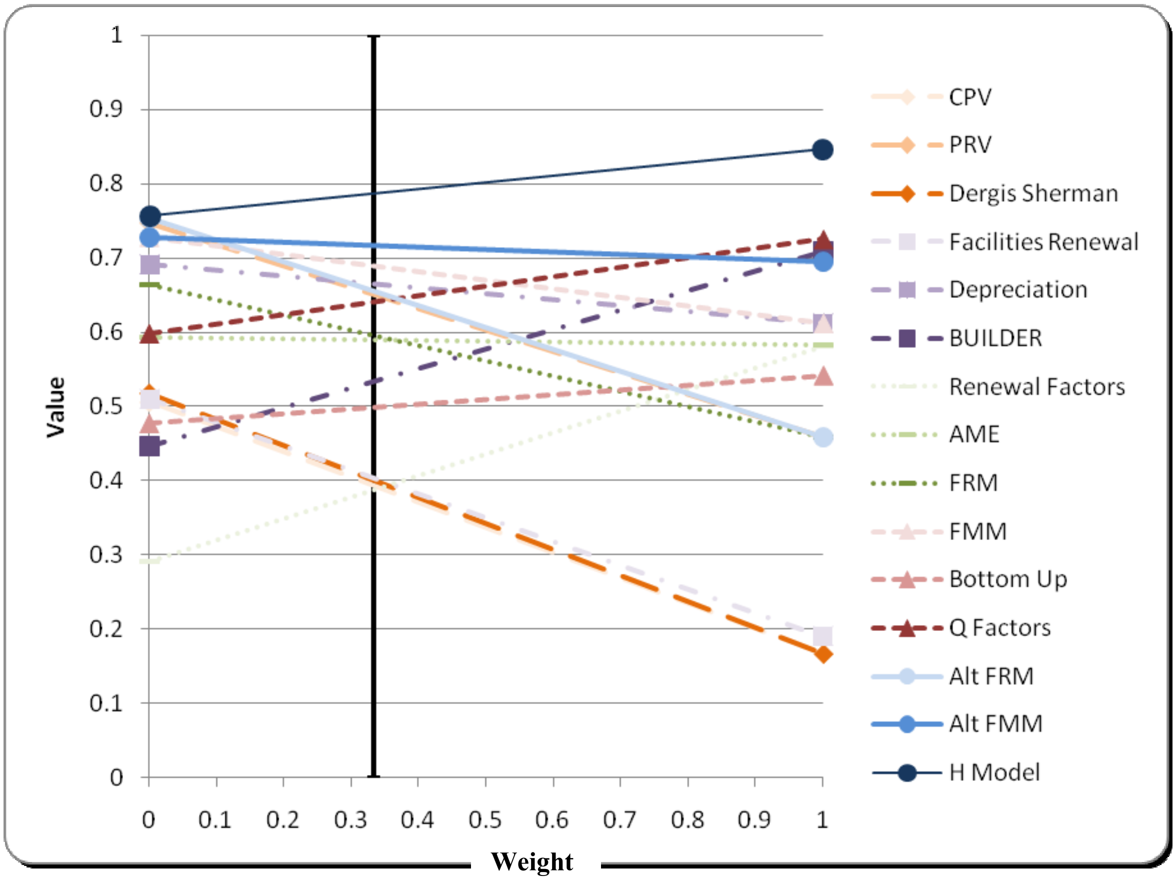


Figure 22. Global Sensitivity of *Prevent Obsolescence*

As stated earlier, if the most preferred alternative is not sensitive to the weight of the first-tier value, then the decision will not be sensitive to the weights of the lower-tier values. However, sensitivities did exist amongst the other alternatives. Therefore, the sensitivity graph of *Predictive Capability* is shown in Figure 23 because it is the second-tier value with the most weight under *Prevent Obsolescence*. The most preferred alternatives (H-Model, Alt FMM, and FMM) are not sensitive to the weight of *Predictive Capability*. If an evaluation measure is categorical, the alternative lines in a sensitivity

graph will merge into groups when the weight of the value goes to 1.0. Even though the SDVF of *Predictive Capability* is continuous, the alternatives received only three scores: 2, 5, or 30-year predictive cycles. Therefore, the sensitivity graph looks like a categorical measure: all the alternative lines merge into the three categories and all of the 30-year alternatives rank highest when the weight of *Predictive Capability* is 1.0.

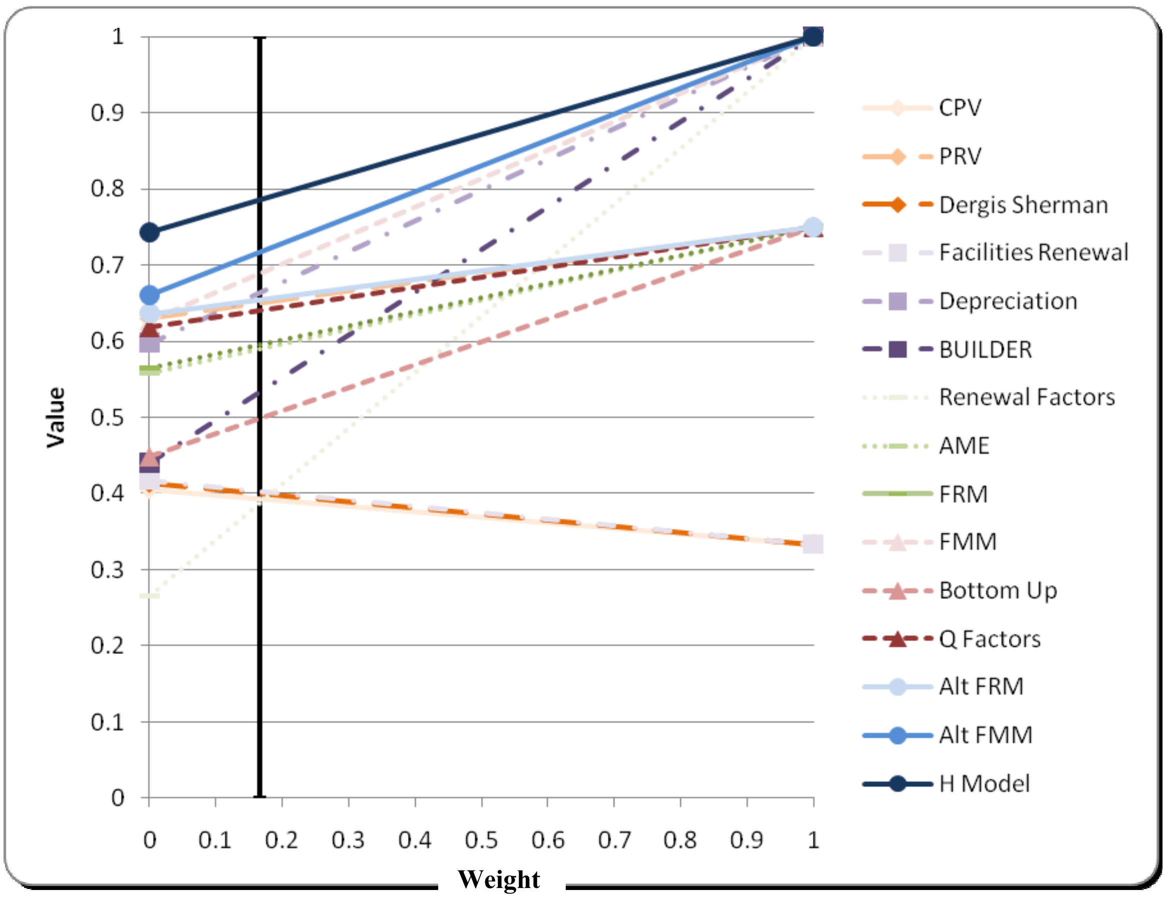


Figure 23. Global Sensitivity of *Predictive Capability*

Sensitivity of *Credibility of Model*

The sensitivity of the decision to the weight of *Credibility of Model* is very similar to that of *Prevent Obsolescence* in that the H-Model is always the preferred alternative regardless of the weight. The sensitivity graph is shown in Figure 24. The current weight of *Credibility of Model* is .556 as shown by the vertical line.

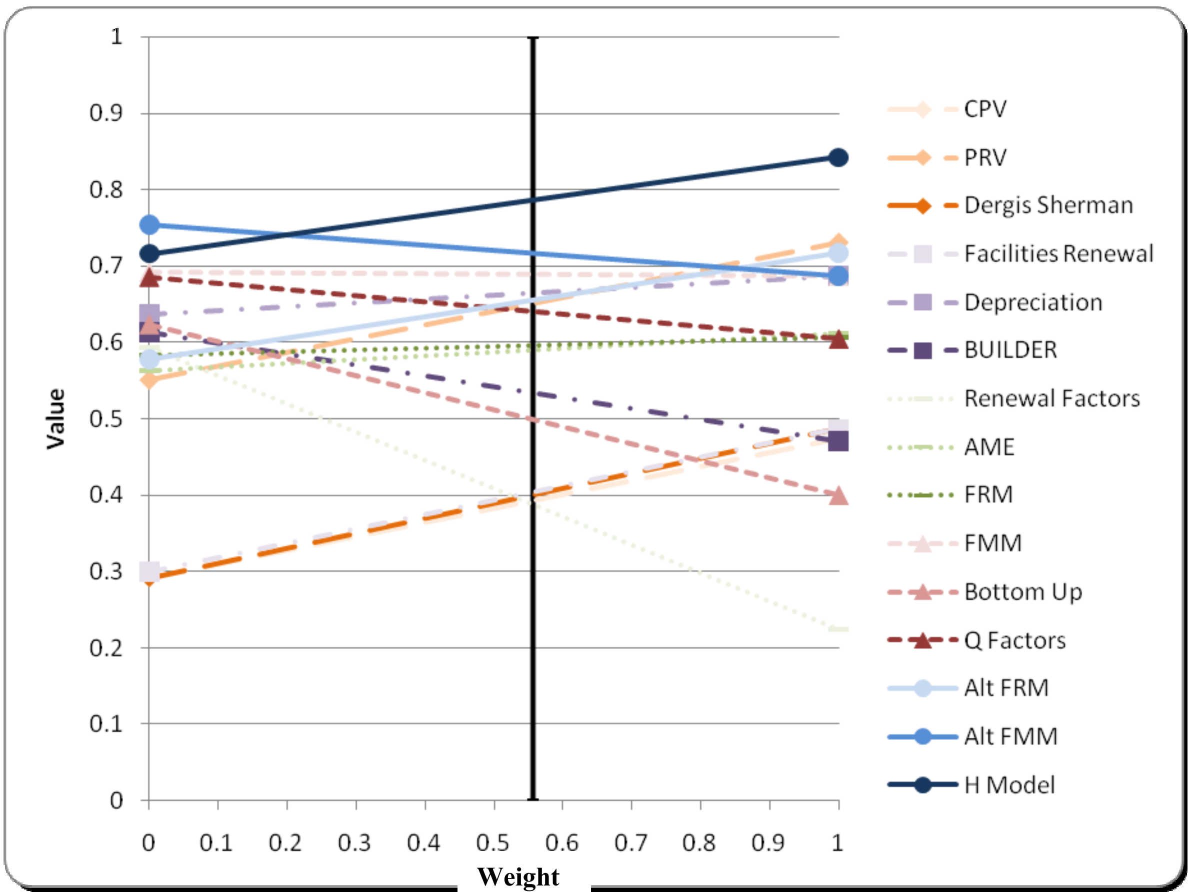


Figure 24. Global Sensitivity of *Credibility of Model*

Even though the decision is not sensitive to the weight of *Credibility of Model*, there are many other areas of sensitivity within the graph. The least preferred alternative is again a close tie between Renewal Factors, Facility Renewal, and Dergis-Sherman. Slight movement to the left or right of the vertical line results in changes to the alternative ranking. The positive sloping lines in this graph are H-Model, Depreciation, Alt FRM, PRV, FRM, Facilities Renewal, Dergis-Sherman, and CPV. These alternatives are all formula based and score well under *Use of Facility Factors* and *Consistency*. The overall value of these alternatives improves as *Credibility of Model* becomes more important to the decision-makers. Again, the lines for FMM and Alt FMM have a negative slope indicating that modifications to the parameters affecting credibility could improve their performance.

There are two bottom tier values under *Credibility of Model* that have high global weights: *Understandable* and *Degree of Consistency*. The sensitivity graphs of those two lower tier values are shown in Figures 25 and 26. Both values are categorical with three categories each, which is why the alternative lines converge into three groups when the value slides to 1.0. *Understandable* is not sensitive to the most preferred alternative but is sensitive to the other alternatives as the weight increases. In *Consistency of Budget Requests*, slight changes in weight causes the ranking of alternatives to change. The H-Model does not perform well in this category as displayed through the negative slope.

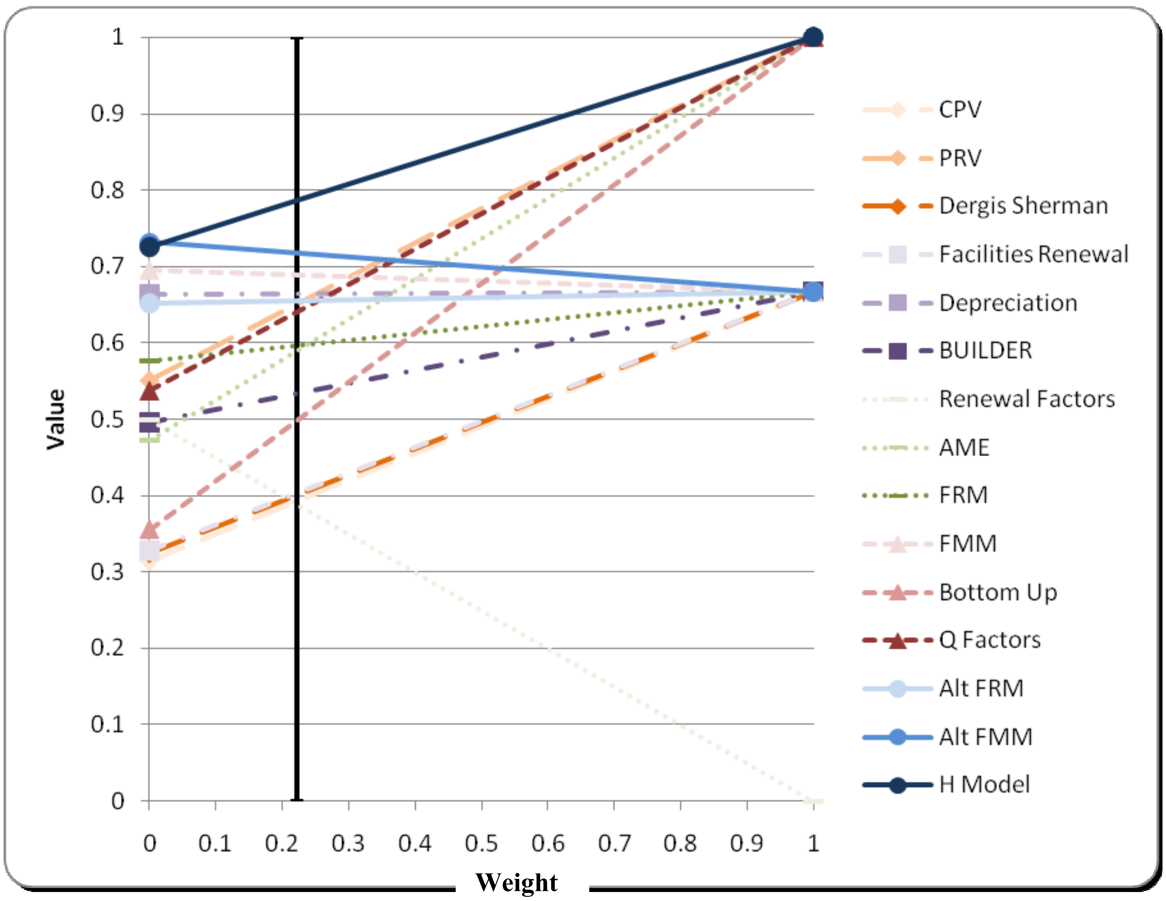


Figure 25. Global Sensitivity of *Understandable*

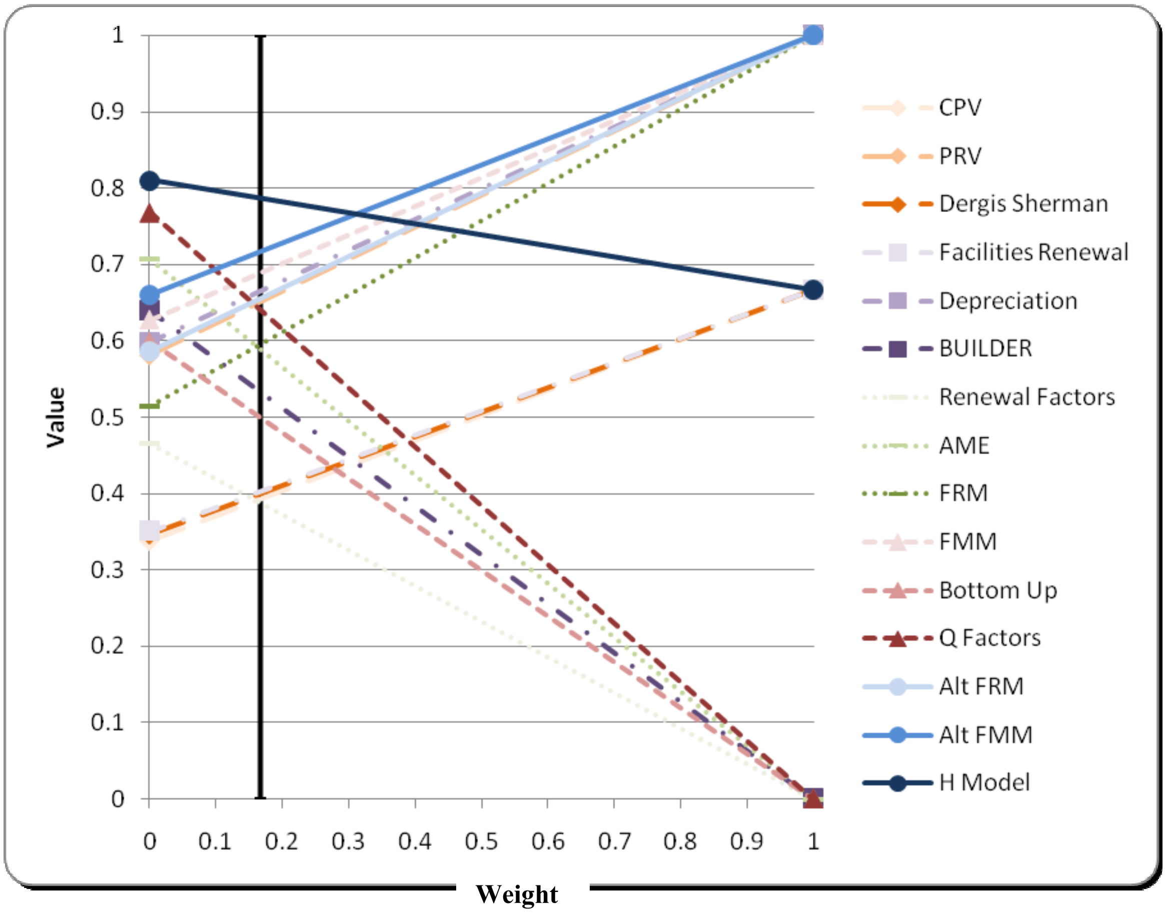


Figure 26. Global Sensitivity of *Consistency of Budget Requests*

<u>Sensitivity of *Implementation*</u>

The most preferred alternative was more sensitive to *Implementation* than the other two first-tier values. Figure 27 is the sensitivity graph of *Implementation*. As the weight of *Implementation* increases from 0.111 to about 0.2, the most preferred alternative changes to Alt FMM. This is not an unrealistic fluctuation because it is likely that a decision-maker within the DoD could place more weight on *Implementation* under

certain circumstances. The alternatives with negative sloping lines in this graph are H-Model, BUILDER, AME, and Q Factors. These alternatives are all condition assessment or life-cycle based models and received the poorest scores under *Implementation*. As *Implementation* becomes more important, their overall value decreases. These alternatives all had positive sloping lines in the *Prevent Obsolescence* graphs. This indicates that they are good models in most categories, but difficult to implement. The sensitivity graphs of the three lower tier values under *Implementation* are very similar to the first tier value and will not be included here.

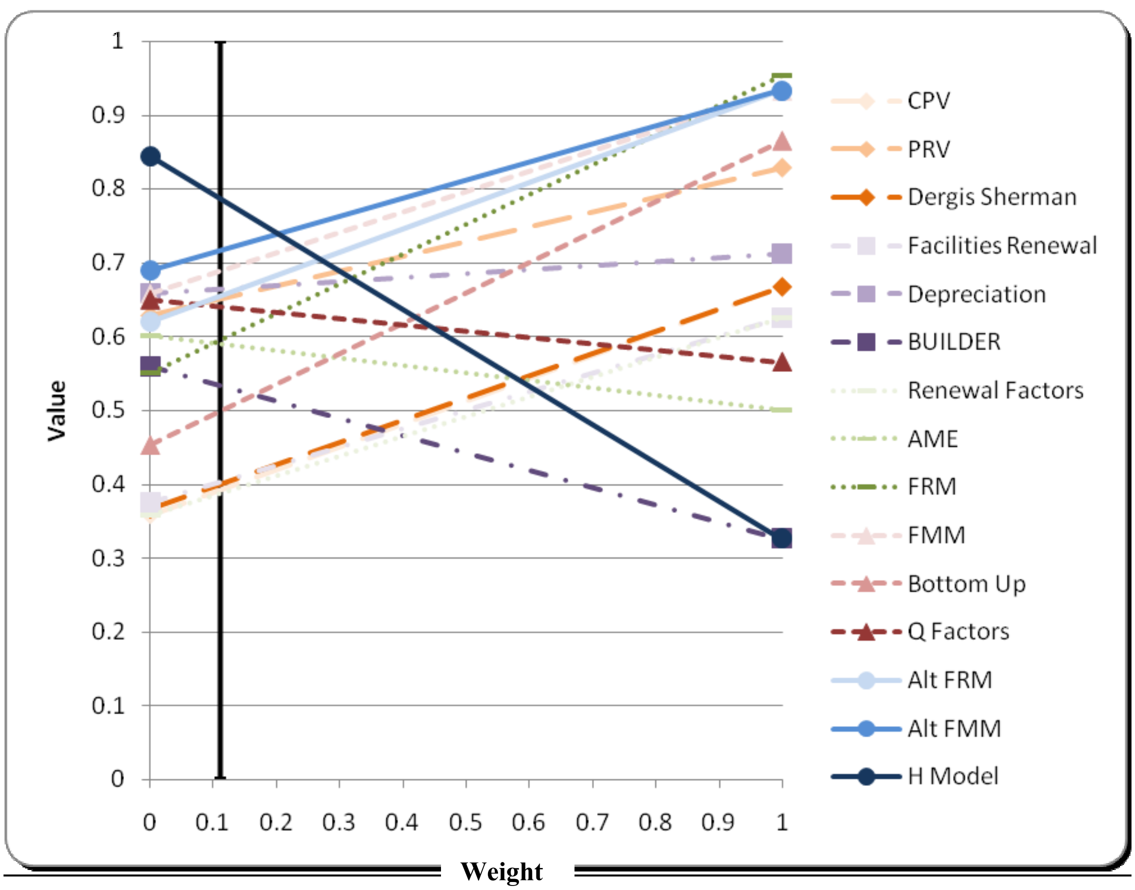


Figure 27. Global Sensitivity of *Implementation*

This completes the deterministic analysis of the value hierarchy. The most preferred alternative was the H-Model; although it was relatively insensitive to weight changes, there are some areas of sensitivity among the other alternatives. This is an important factor since the H-Model was created specifically from the value hierarchy. If decision-makers are not willing to implement the model, they should be cautious of the various sensitivities of the other models. Additionally, by observing the negative sloping alternative lines within the graphs, the decision-makers can see potential areas of improvement that would increase the overall value of the alternative.

Probabilistic Analysis

The analysis to this point has ignored areas of uncertainty that need to be addressed to determine the impact on the alternatives. Therefore, this section is dedicated to analyzing the effect of uncertainty in the model, which exists in the scores given to *Implementation*. Specifically, two types of analysis were performed to gain further confidence in the model outcomes. First, the DM's risk behavior was assessed using an expected utility analysis to determine the impact of the uncertain scores. Second, an additional sensitivity analysis of the DM's risk tolerance level was performed to determine if the probabilistic ranges and risk behavior have an impact on the alternative rankings.

Risk Tolerance

The first step in the probabilistic analysis is to determine the decision-maker's multi-attribute risk tolerance (ρ_m). The procedure to calculate ρ_m was described in

Chapter II through the alternative lottery where the DM was given a 50/50 chance of the best case or worst case scenario and asked to define a hypothetical alternative that would make him/her indifferent to playing the lottery. The DM chose the lowest acceptable level for each evaluation measure; slight modifications were then made to these scores until the DM was indifferent between the lottery and the value of the hypothetical alternative. Using this method, the value of the hypothetical alternative was calculated to be 0.184. The corresponding ρ_m for this value was found to be 0.269 and indicates risk-averse behavior from the decision-maker (Kirkwood, 1997). A summary of the best, worst, and hypothetical alternatives is located in Table 9.

Table 9. Summary for Determining ρ_m

	Worst Alt	Best Alt		Indifferent Alternative Scores	Value	Weight	Weighted Value
Planning Horizon	0	30		3	0.5	0.1665	0.08325
% of Method that is Condition Based	0	100		0	0	0.0444	0.00000
% of Method that is Life-Cycle Based	0	100		0	0	0.0388	0.00000
Empirical Support	Low	High		Low	0	0.0277	0.00000
Degree of Sensitivity	Low	High		Low	0	0.0556	0.00000
Degree of Comprehension	Low	High		Low	0	0.2224	0.00000
# of Fac Types Used	0	200		0	0	0.1001	0.00000
# of Type A Factors Used	0	5		2	0.4	0.0334	0.01334
# of Type B Factors Used	0	6		2	0.333333	0.0234	0.00778
# of Type C Factors Used	0	3		0	0	0.0100	0.00000
Degree of Consistency	Low	High		Med	0.67	0.0333	0.02231
# of DoD Hrs/yr	2000	0		1000	0.25	0.0185	0.00463
# of PM Hrs/yr	2000	0		2000	0	0.037	0.00000
# of Base/MAJCOM Hrs/yr	2000	0		100	0.95	0.0555	0.05273
Total Value	0	1				$Z_{0.5}$ =	0.18405
					ρ_m = 0.269 (Risk Averse)		

The risk behavior can also be expressed in terms of a utility function, or graph of the risk behavior. The shape of the utility curve denotes the DM's risk attitude; a concave curve denotes risk aversion, while a convex curve denotes risk seeking. Being risk averse, as most decision-makers are when making decisions for their profession, means that the DM would trade a gamble for a sure amount, even if it is less than the expected value of the gamble (Clemen & Reilly, 2001). This utility curve can be plotted on a graph using the following equation (Clemen & Reilly, 2001):

$$U(x) = 1 - e^{(-x/\rho m)} \tag{19}$$

where U(x) represents the utility of some value (x) and ρ_m is the multi-attribute risk tolerance (0.269 for this group of DMs). The resulting graph is shown in Figure 28.

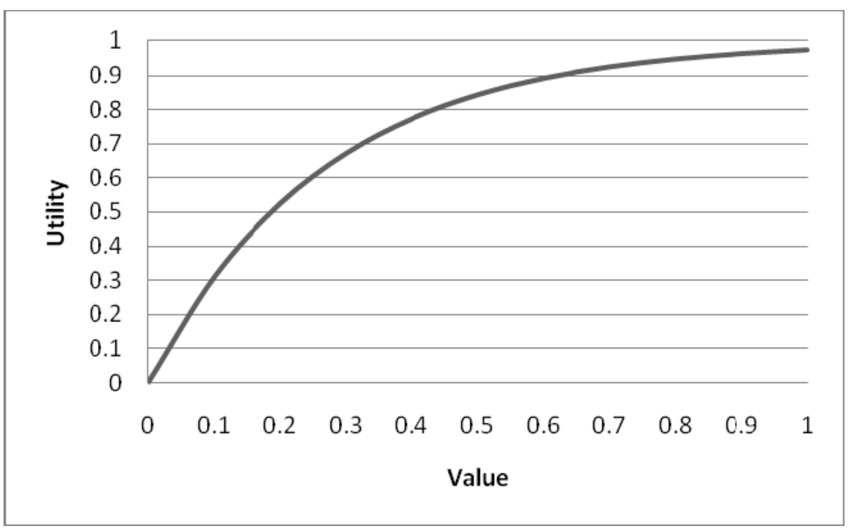


Figure 28. Utility Function of DM (ρ_m =0.269)

Expected Utility

Once the ρ_m is known, the expected utility (E(U)) of the outcomes can be calculated using the power additive utility function equation. There were 27 possible outcomes to consider for each alternative; a summarized outcome of the expected utilities is shown in Table 10. The data and calculation results are located in Appendix E. In addition to the E(U) analysis, the expected values were also calculated by taking an average of the values of each uncertain measure (probability * value). The data and calculations used for the expected value analysis are located in Appendix D.

Table 10. Summary of Expected Utility Values

	Deterministic Analysis		**Probabilistic Analyses**			
	Value Analysis		**Expected Value Analysis**		**Expected Utility Analysis**	
Rank	**Alternative**	**Value**	**Alternative**	**Expected Value**	**Alt**	**EU**
1	*H-Model*	0.7865	*H-Model*	0.7860	*H-Model*	0.9697
2	*Alt FMM*	0.7176	*Alt FMM*	0.7177	*Alt FMM*	0.9538
3	*FMM*	0.6899	*FMM*	0.6900	*FMM*	0.9461
4	*Dep*	0.6653	*Dep*	0.6648	*Dep*	0.9383
5	*Alt FRM*	0.6558	*Alt FRM*	0.6552	*Alt FRM*	0.9352
6	*PRV*	0.6504	*PRV*	0.6503	*PRV*	0.9336
7	*Q Fact*	0.6400	*Q Fact*	0.6394	*Q Fact*	0.9297
8	*FRM*	0.5964	*FRM*	0.5964	*FRM*	0.9132
9	*AME*	0.5894	*AME*	0.5889	*AME*	0.9100
10	*BUILDER*	0.5343	*BUILDER*	0.5338	*BUILDER*	0.8840
11	*Bottom Up*	0.4989	*Bottom Up*	0.5001	*Bottom Up*	0.8691
12	*Fac Ren*	0.4044	*Fac Ren*	0.4051	*Fac Ren*	0.7975
13	*Dergis Sherman*	0.4013	*Dergis Sherman*	0.4013	*Dergis Sherman*	0.7943
14	*CPV*	0.3942	*CPV*	0.3942	*CPV*	0.7880
15	*Renewal Fact*	0.3876	*Renewal Fact*	0.3871	*Renewal Fact*	0.7817

As shown in Table 10, the ranking of alternatives remains the same throughout all the analyses. The scores of the E(U) analysis are high because the DMs are risk averse and all the possible alternatives score well compared to the hypothetical alternative shown in Table 9. Typically, alternatives with more uncertainty will score lower than those with less uncertainty. However, there was no impact of the uncertain scores on the alternative rankings because of the low weight associated with the *Implementation* values.

To illustrate the potential impact of the uncertainties, the deterministic and probabilistic analyses were recalculated for a hypothetical case where the weight of *Implementation* increased to 0.333. This weight was chosen as a realistic scenario where the decision-makers change their preferences of the first-tier values. As shown in Figure 27, the alternative rankings change as the weight of *Implementation* increases past about 0.2. To keep the ratio of weights consistent, the weights of Prevent Obsolescence and Credible Model change to 0.25 and 0.417, respectively. Table 11 shows a summary of the new deterministic and probabilistic rankings.

Table 11. Summary Table for Revised Weight of *Implementation*

	Deterministic Analysis		**Probabilistic Analyses**			
	Value Analysis		**Expected Value Analysis**		**Expected Utility Analysis**	
Rank	**Alternative**	**Value**	**Alternative**	**Expected Value**	**Alt**	**EU**
1	*Alt FMM*	0.7241	*Alt FMM*	0.7242	*Alt FMM*	0.9667
2	*FMM*	0.7031	*FMM*	0.7032	*FMM*	0.9620
3	*Alt FRM*	0.6789	*Alt FRM*	0.6778	*Alt FRM*	0.9553
4	*PRV*	0.6549	*PRV*	0.6548	*PRV*	0.9474
5	*Depreciation*	0.6506	*Depreciation*	0.6505	*FRM*	0.9447
6	*H-Model*	0.6446	*H Model*	0.6431	*Depreciation*	0.9416
7	*FRM*	0.6381	*FRM*	0.6381	*H-Model*	0.9396
8	*Q Factors*	0.5703	*Q Factors*	0.5685	*Q Factors*	0.9223
9	*Bottom Up*	0.5391	*Bottom Up*	0.5427	*Bottom Up*	0.9141
10	*AME*	0.5298	*AME*	0.5287	*AME*	0.8990
11	*BUILDER*	0.4573	*BUILDER*	0.4557	*BUILDER*	0.8525
12	*Dergis Sherman*	0.4374	*Dergis Sherman*	0.4374	*Dergis Sherman*	0.8444
13	*CPV*	0.4321	*CPV*	0.4321	*CPV*	0.8407
14	*Fac Ren*	0.4294	*Fac Ren*	0.4314	*Fac Ren*	0.8403
15	*Renewal Fact*	0.4094	*Renewal Fact*	0.4084	*Renewal Fact*	0.8283

As Table 11 shows, increasing the weight of *Implementation* to 0.333 and altering the weights of the other first-tier values accordingly, the deterministic rankings change from the model results in Table 10. Additionally, the rankings change between the deterministic and probabilistic analyses in Table 11. More weight was placed on the value with uncertainty which explains the changes in rankings. One major change between the Value analysis and the E(U) analysis which illustrates the effect of uncertainty is that FRM moved up in ranking. FRM is the model with the least uncertainty because it is the model currently in use; therefore, the decision-makers were

able to provide a smaller range of implementation hours. This shows how alternatives with less uncertainty will score better for a risk averse decision maker.

In addition to the E(U) analysis, a second method for incorporating uncertainty is the Certainty Equivalent (CE) analysis. The resulting ranked order of alternatives using CE is always the same as the E(U) analysis; therefore, all the CE descriptions and calculations are included as supplemental information in Appendix F. The CE is a useful analysis to ensure accuracy between the two probabilistic analyses. The E(U) found that the uncertainty had no impact on the alternative rankings at the given weights; however, if the weight of *Implementation* increases, then uncertainty has more impact on the results. At this point, the impact of the decision-maker's risk preference (ρ_m) is not known and will be determined next through a sensitivity analysis.

Sensitivity Analysis of Risk Tolerance (ρ_m)

In the deterministic analysis, sensitivity was assessed by varying the weights of the values to determine if the ranking of alternatives changed. In the probabilistic analysis, sensitivity is assessed by varying ρ_m to determine if the risk behavior of the decision-makers has any bearing on the alternative ranking. Using the E(U) calculations, the utility values were found for each alternative as ρ_m was varied from -0.1 to 0.1 as shown in Table 12. In all cases, the ranked order of alternatives did not change no matter what value ρ_m assumed. The H-Model remained the best alternative and the order of the rest of the alternatives remained the same, demonstrating that the results were not dependent on ρ_m; therefore, the results are considered to be independent of the decision-

maker's risk behavior. This same procedure of varying ρ_m was applied to the CE calculations and the results are shown in Appendix F.

Table 12. Sensitivity Analysis of ρ_m

ρ_m =	**0.269**		**Risk Seeking**		**Risk Neutral**	**Risk Averse**	
Alternative	**E(U)**		$\rho_m = -.1$	$\rho_m = -0.5$	$\rho_m = 10$	$\rho_m = 0.5$	$\rho_m = .1$
H-Model	0.9697		0.1180	0.5974	0.7943	0.9164	0.9997
Alt FMM	0.9538		0.0594	0.5011	0.7278	0.8812	0.9993
FMM	0.9461		0.0450	0.4656	0.7006	0.8656	0.9990
Dep	0.9383		0.0350	0.4351	0.6759	0.8505	0.9987
Alt FRM	0.9352		0.0318	0.4238	0.6665	0.8446	0.9986
PRV	0.9297		0.0271	0.4058	0.6509	0.8346	0.9984
Q Fact	0.9183		0.0199	0.3723	0.6206	0.8142	0.9978
FRM	0.9132		0.0176	0.3594	0.6083	0.8056	0.9975
AME	0.9100		0.0164	0.3518	0.6010	0.8003	0.9973
BUILDER	0.8840		0.0094	0.2988	0.5462	0.7588	0.9952
Bottom Up	0.8691		0.0072	0.2748	0.5192	0.7367	0.9937
Fac Ren	0.7975		0.0026	0.1954	0.4172	0.6421	0.9826
Dergis Sherman	0.7943		0.0025	0.1927	0.4133	0.6382	0.9819
CPV	0.7880		0.0023	0.1878	0.4061	0.6307	0.9806
Renewal Fact	0.7817		0.0021	0.1830	0.3990	0.6232	0.9791

To illustrate the potential impact of a change in risk tolerance level, another realistic scenario was created where the range of scores for the *Implementation* measures of the FMM alternative were increased to each cover the entire range of 0-2000 hours. The results are located in Table 13. The results show that the ranking of FMM increases for a risk seeking decision-maker and decreases for an extremely risk averse decision-maker.

Table 13. Revised Sensitivity of ρ_m

ρ_m =	0.269		Risk Seeking		Risk Neutral	Risk Averse	
Alternative	**E(U)**		**ρ_m = -.1**	**ρ_m =-0.5**	**ρ_m =10**	**ρ_m =0.5**	**ρ_m =.1**
Alt FMM	0.9667		0.1020	0.5762	0.78	0.9095	0.9996
Alt FRM	0.9553		0.0630	0.5087	0.7334	0.8844	0.9993
PRV	0.9474		0.0472	0.4715	0.7052	0.8683	0.9991
FRM	0.9456		0.0443	0.4636	0.6990	0.8646	0.9990
FMM	0.9435		0.0576	0.4765	0.7035	0.8639	0.9986
Depreciation	0.9416		0.0393	0.4480	0.6863	0.8569	0.9989
H-Model	0.9396		0.0377	0.4415	0.6807	0.8532	0.9988
Q Factors	0.9223		0.0224	0.3840	0.6312	0.8214	0.9980
Bottom Up	0.9120		0.0175	0.3572	0.6059	0.8037	0.9974
AME	0.8990		0.0134	0.3292	0.5777	0.7827	0.9964
BUILDER	0.8525		0.0056	0.2531	0.4930	0.7137	0.9916
Derg-Sherman	0.8444		0.0049	0.2423	0.4800	0.7023	0.9906
CPV	0.8407		0.0046	0.2381	0.4746	0.6974	0.9901
Fac Ren	0.8403		0.0046	0.2376	0.4740	0.6968	0.9900
Renewal Fact	0.8283		0.0040	0.2254	0.4577	0.6813	0.9880

Summary

This chapter presented the specifics of steps 7 through 9 of the VFT process and included both a deterministic and probabilistic analysis of the VFT model. In every analysis, the H-Model was found to be the most preferred alternative with very few sensitivity issues; however, the ranked order of the rest of the alternatives are very sensitive to weight changes. Additionally, there were no changes of the ranking of alternatives between the deterministic and probabilistic analyses showing that uncertainty had no impact on the model results. However, as shown through one scenario where the weight of *Implementation* was increased, there are several changes in both the

deterministic and probabilistic analyses. The DM's risk behavior was found to be irrelevant to the outcome. However, one scenario where the range of scores for the FMM alternative was increased showed the potential impact that risk behavior could have on the results. Knowing that the model outcomes are independent of the uncertainties and the risk behavior should increase the decision-makers' confidence in their decision. The next and final chapter will present the last step of the VFT process.

V. Conclusions and Recommendations

This chapter completes the last step of the ten-step Value Focused Thinking (VFT) process by presenting conclusions and recommendations (Shoviak, 2001). Additionally, the overall research effort is summarized by presenting the answers to the research questions posed in Chapter I. Finally, the strengths and limitations of the model are presented along with recommendations for future research.

Research Summary

The purpose of this research was to provide a tool to enable Department of Defense (DoD) decision-makers to analyze the performance of various facility recapitalization budgeting models and select the most preferred model. As a result, the decision-makers should gain the confidence and support necessary to effectively execute the recapitalization program for the DoD. The decision model is easily modifiable so that future analysis can be conducted as new alternatives arise and values change. The five investigative research questions posed in Chapter I were answered through both a literature review and the creation and analysis of the VFT model. Each question and a summary of the findings are presented below.

1. What are the long term effects of under-funding the maintenance of facilities? As addressed in Chapter II and shown in Figure 1, a facility will lose service life if not maintained properly. A potential result of deferred maintenance, without a recapitalization effort, is facility obsolescence and eventually failure. However, early and consistent investment in facility maintenance and repair can prevent unnecessary wear

and tear and avoid the consequences of emergency repairs, mission disruption, and employee health. As Jefson (2005) showed in his research, it is difficult to recover from a lack of proper maintenance without a recapitalization project because of the synergistic decline in performance.

2. What methods currently exist and are used for estimating recapitalization requirements in both public and private sectors? The academic literature and DoD publications summarized in Chapter II contained ten potential models for consideration, as shown in Table 3. The models fell into one of three categories: Formula-Based Models, Condition Assessment Models, and Life-Cycle Based Models.

3. What is the appropriate methodology for determining the best recapitalization estimation method for the DoD? Decision analysis is appropriate when the nature of the decision being confronted is complex, has uncertain outcomes depending on the alternative chosen, has different conclusions based on different perspectives, and often has multiple, competing objectives (Clemen and Reilly, 2001). The nature of the problem being addressed in this thesis meets all these characteristics; therefore, a decision analysis technique is an appropriate methodology. Between the two major decision analysis approaches for this type of problem, VFT was found to be the best method for analyzing this problem.

4. What values are important to the DoD decision-makers for selection of the best recapitalization method? The second step in the VFT process required the decision panel to create a value hierarchy that is complete, non-redundant, preferentially independent, operable, and small in size (Kirkwood, 1997). Through a consultation process with the decision panel, the hierarchy was established and is shown in Figure 19.

5. *What is the most preferred method for DoD facility recapitalization budget estimation?* The H-Model was the most preferred alternative in every analysis; however, it was also a hypothetical model with the most idealistic scores in the realm of possibility. The order of the remaining alternatives was very sensitive to weight changes. In application, the characteristics of the H-Model should be implemented into the existing or proposed models to ensure that any model being used meets the values of the decision-makers to the maximum extent possible. The Alt FMM and Depreciation models scored very high and could, with little difficulty, be implemented as the DoD's recapitalization model. If the weight placed on *Implementation* were to increase significantly, the Alt FMM would be preferred to the H-Model.

6. *What are the decision-makers' risk behaviors with regard to recapitalization models and do they have an effect on the preferred result?* Through the process detailed in Chapter II, the multi-attribute risk tolerance (ρ_m) of the decision-makers was assessed; the decision-makers were subsequently considered risk averse ($\rho_m = 0.269$). Sensitivity analysis showed that the alternative rankings were independent of the decision-makers' risk tolerance level. Additionally, the ranking of alternatives in the deterministic analysis was the same as the ranking in the probabilistic analyses. This means that the alternative rankings were also not sensitive to the probabilities included in alternative scores in the *Implementation* values, and the preferred alternative was consistent throughout. However, an increase in the weight of *Implementation* has a significant impact on the preferred alternative and the alternative rankings. Additionally, an increase in the amount of uncertainty in the model could result in changes to the results as the decision-maker's risk behavior changes.

Value Model Benefits

The value model created through this research is defensible to decision-makers because it was developed systematically and objectively by a panel of subject matter experts. By establishing a value hierarchy before considering alternatives, the value model is objective, more complete, and free from potential bias that could influence the selection of alternatives had alternative focused thinking been used. The model development process can be easily repeated; additionally, the model could be modified to meet the preferences and needs of other stakeholders in the future. The model results enable the decision panel to increase their confidence in the chosen alternative and help them to defend the alternative with quantifiable evidence of the decision.

Limitations

There are five primary limitations associated with this research. First, it is difficult to compare an organization as large as the DoD with those in the private sector. The DoD's facility management program has perpetual modernization requirements that are estimated and budgeted for annually, which is unparalleled by any other known organization. Therefore, using existing evidence from literature to score some of the alternatives might not be directly applicable to the DoD in the same way. Second, some subjectivity is inherent in this research because the result is based on the opinions of subject matter experts. These experts are aware of the values and objectives of the ultimate decision-maker, but do not have the authority to make the final decision on which method the DoD will use to estimate recapitalization. Third, this thesis used a panel of decision-makers and with multiple decision-makers comes a variety of opinions.

Every effort was made to establish consensus; however, any irreconcilable disagreements were deferred to the ranking panel member (the DoD Recapitalization Program Manager). Fourth, this model is only applicable to the set of decision-makers used to establish the value hierarchy. Another interested stakeholder could only apply these results if their values and weighting preferences were exactly the same as the DoD decision panel. However, as stated in the model benefits section, the process to create the model can be used to establish a new hierarchy. A fifth and final limitation is that the model ignored all cost figures because of the high level of effort and uncertainty required in providing estimates. There were too many unknowns in each of the alternatives to establish good cost estimates for implementation.

Future Research

There are several areas for potential future research. As stated in Chapter I, executive level leaders need to be convinced of the need for recapitalization. One convincing area that is under-researched is the amount of future cost that could be avoided by execution of properly timed maintenance or recapitalization projects. Second, finding parallels between the DoD's recapitalization process and any other organization that requires annual budgeting would be extremely useful to DoD decision-makers. Third, research that enhances existing knowledge on predicted facility lives by facility type is needed to ensure the accurate predictive capability of budgeting models. Finally, a systems perspective on how the money, once allocated, is actually spent would add insight to the entire appropriations process.

Conclusions

This research has shown that the existing recapitalization model used by the DoD, the Facilities Recapitalization Model (FRM), was inferior to other potential models that could easily be used by the DoD. The deterministic and probabilistic analyses along with the sensitivity analyses found that the H-Model was the most preferred model across the board, regardless of risk behavior or uncertainty. The proposed future model for the DoD, the Facilities Modernization Model (FMM), performed well according to the value model; however, the FMM could perform even better with some slight modifications. By focusing on the values and methods established in this thesis, the recapitalization program managers can continue to improve the accuracy and defensibility of budget models to ensure proper asset management of the nation's largest inventory of facilities and efficient use of public funds.

Appendix A – Evaluation Measure Definitions

Definitions of Measures under *Prevent Obsolescence*

Measure	Definition
Planning Horizon	Subject matter experts agreed that the best predictive tool for obsolescence is to ensure that program managers are thinking about and planning beyond 3-5 years horizon. Therefore, planning horizon is used as a proxy for the predictive capability of the method being evaluated. The longer the planning horizon, the better the model will be in planning, predicting, and preventing obsolescence.
% of Method that is Condition Based	A general consensus from literature and industry experts is that condition based assessments provide the most accurate prediction of recapitalization requirements. Therefore, methods based on standardized condition inspection procedures is considered a good industry standard. In order for the method to be considered as condition based and receive a score greater than zero in this category, the following conditions must be met: (1) Method must be published in peer-reviewed literature and shown to have empirical support, or (2) Method must have detailed inspection procedures and a training program that has been reviewed and found acceptable by experts in the field, and (3) Inspectors must have annual refresher training, at minimum. If either condition (1) or (2) is met and condition (3) is met then the method will receive a score based on the percent of the recapitalization budget that is based on the condition assessment results.
% of Method that is Life-Cycle Based	Like condition assessments, literature and industry experts have found value and support for life-cycle based methods of recapitalization budgeting. Although not as accurate in representing the actual recap needs, life-cycle methods are still valuable tools in predicting and preventing obsolescence. In order for the method to be considered as life-cycle based and receive a score greater than zero, the following conditions must be met: (1) Method must be published in peer-reviewed literature and shown to have empirical support, or (2) Method must detail the break-down of facility sub-systems and sources of life-cycle data that has been reviewed and found acceptable by experts in the field. If either of the conditions is met, the method will receive a score based on the percent of the recapitalization budget that is based on life-cycle assessment.

Empirical Support	Subject matter experts also found that there were other methods and models that have shown to have empirical support in the literature that were not condition or life-cycle based. The experts see value in methods with peer-reviewed approval and results shown to be effective in practice. Therefore this is a yes/no measure where full value is realized if the model is supported in literature or by affirmation from industry experts to any degree. If there is any doubt to the support or no support is published and the method is not tested or well known, then the method will receive a score of zero.
Degree of Sensitivity	The decision panel recognized that the amount budgeted for recapitalization is sensitive to the investment behavior of the asset managers. The budget will fluctuate greatly based on the planned recapitalization methods such as replacement or renovations. Therefore it is valuable to plan for the investment method and track historic investment behavior. This measurement scale is constructed and defined as follows: **High** - Model distinguishes between facilities recapitalized through renovation and replacement and budgets for them separately **Med** - Model uses an average between renovation and replacement as a constant **Low** - model does not distinguish between recapitalization methods

Definitions of Measures under *Credible Model*

Degree of Comprehension	Understandability from the perspective of non-technically trained decision-makers with authority to approve and allocate funds (for the DoD includes Congress and executive level military leaders) is key for recapitalization methods. Therefore, this category is judged from that perspective rather than the perspective of a subject matter expert or program manager. The degree of comprehension scale is constructed and defined as follows: **Well Understood** - Method parameters are commonly understood and logical and can be conveyed easily upon first explanation, or parameters are similar to others already understood by decision-makers. Metric used as benchmark is intuitive and requires little explanation. **Moderately Understood** - Method parameters are slightly difficult to comprehend, but could be understood through one or two explanations by experts, or method is new and not used previously in any other budget model. Metric used as benchmark is intuitive and requires some or no explanation. **Not Understood** - Method is highly technical or includes confusing parameters that cannot be easily explained to non-technically trained decision-makers. Metric used as a benchmark is not intuitive.
# of Fac Types Used	Research has shown that different types of facilities have different expected service lives; therefore, consideration of the differences between facility types has value to the decision panel and provides integrity of the model inputs. The more types considered the better; however, the service lives of each facility type must be based on peer-reviewed research or accepted by the decision panel as valid. If the facility types are valid, the score given for this measure is directly measured as the number of facility types used.
# of Type A Factors Used	Another way to provide integrity to the model inputs are the use of facility factors. There are many factors available and commonly used in budgeting, but some factors are more accurate than others. To measure this value accurately and directly the facility factors were classified by the decision panel as Type A, B, or C. Type A factors are based on peer-reviewed research and are commonly accepted by industry experts as valid factors used for recap budgeting. Type A factors include: Area Cost Factor, Plant Replacement Value, Replacement Cost Factor, Facility Priority (Mission essential, Mission support, etc), and Facility Age. This measure is scored directly based on the number of factors used in the model.

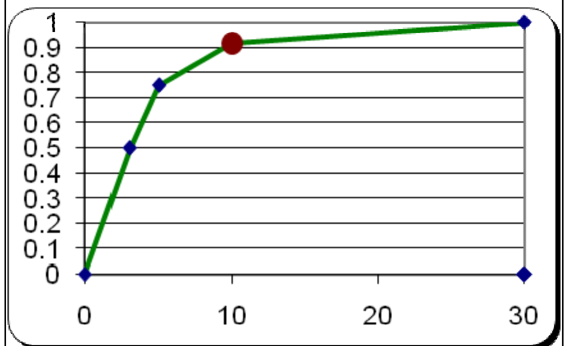
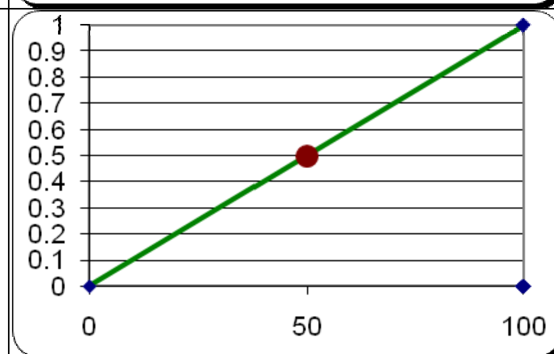
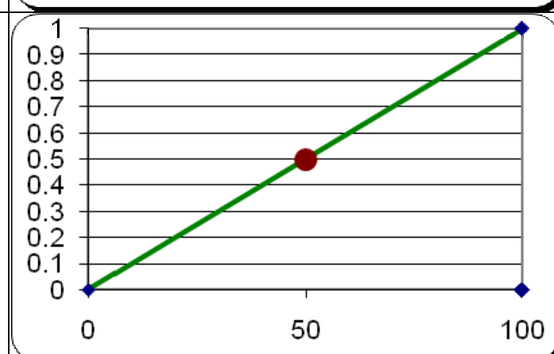
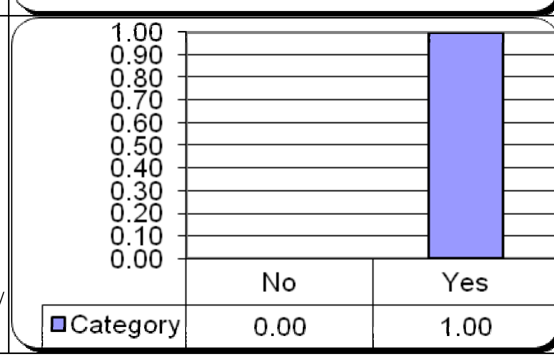
# of Type B Factors Used	Type B factors are defined as those factors that are mentioned in literature but have not received empirical support for use in recapitalization budgets or those that are known by the decision panel but are unsure of their level of use in practice. Type B factors include: Current Replacement Value or (market value), percent of project backlog, construction type factor, climate, deferred maintenance penalties, demolition factor.
# of Type C Factors Used	Type C factors are defined as those that serve as proxy measures for budgeting for recapitalization. Type C factors include: Percentage of previous budgets, size factors, and depreciated value.
Degree of Consistency	Methods that provide budget estimates that vary widely from year to year seem unreliable and not credible from the perspective of decision-makers. It is difficult to define the exact degree of fluctuation that can be expected in each model therefore a constructed, categorical scale is used to estimate the degree of attainment. The constructed scale is defined as follows: **Consistent** - Budget requests are expected to be close to the same amount each year, with the exception of slight increases with inflation rates. **Moderately Consistent** - Budget requests are expected to fluctuate slightly due to the model's consideration of certain factors that are known to change each year, such as project backlog and construction cost factors. **Inconsistent** - Budget is expected to fluctuate greatly or the degree of consistency cannot be predicted.

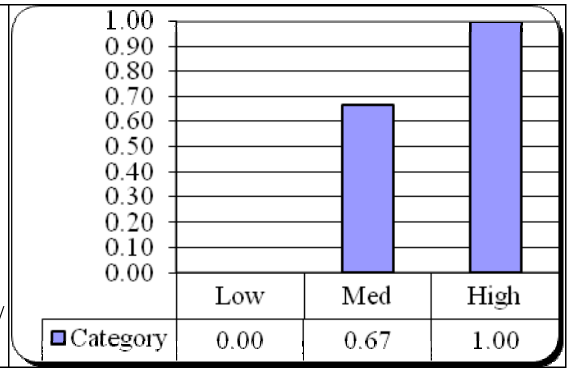
Definitions of Measures under *Implementation*

DoD Hours	Models that are easily implemented and do not require extra work from employees at various levels are desirable. This value is measured directly as the estimated number of hours required each year by the DoD program managers to implement and run the model, where less is better.
PM Hours	This value is measured directly as the estimated number of hours required each year by the recap program managers at each service HQ level to implement and run the model, where less is better.
Base Hours	This value is measured directly as the estimated number of hours required each year by the MAJCOM or base level personnel to implement and run the model, where less is better.

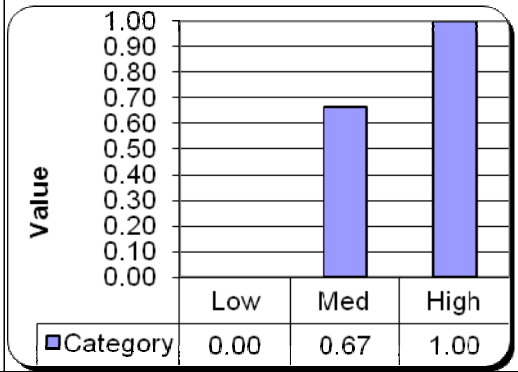
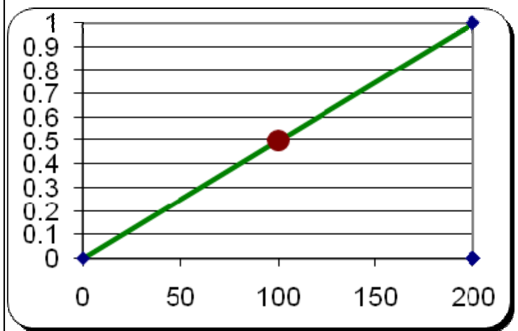
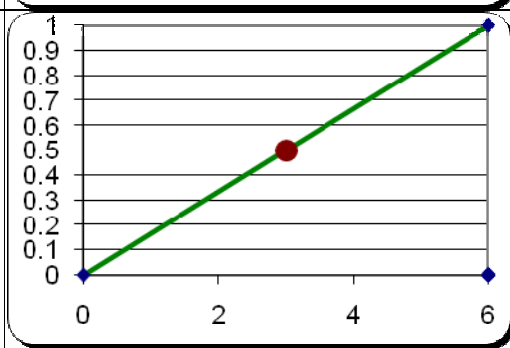
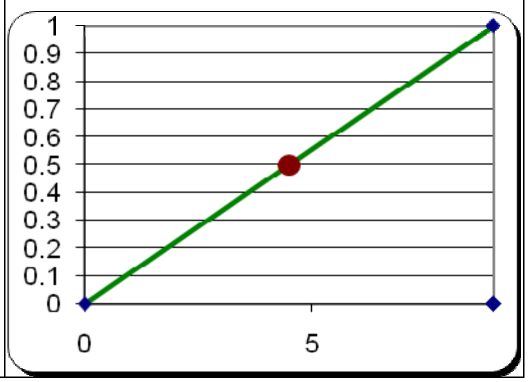
Appendix B – Summary of Measures and SDVFs

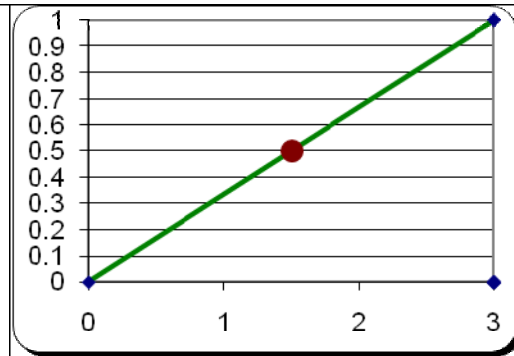
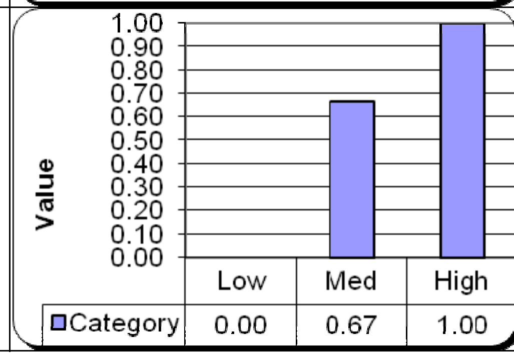
Summary of *Prevent Obsolescence* Branch

Value	Measure	Measure Unit	Measure Type	Single Dimensional Value Function
Predictive Capability	Planning Horizon	Years	Natural/ Proxy	
Condition Assessment Method	% of Method that is Condition Based	%	Natural/ Direct	
Life-Cycle Based Method	% of Method that is Life-Cycle Based	%	Natural/ Direct	
Method with Empirical Results	Empirical Support	Binary	Constructed/ Direct	

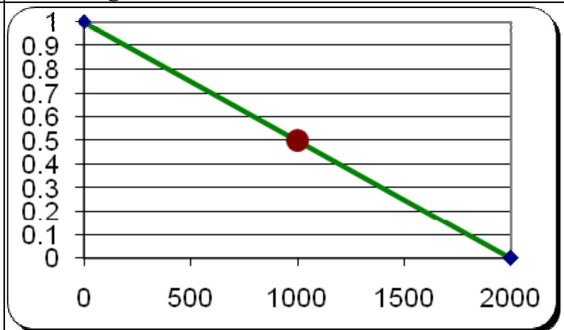
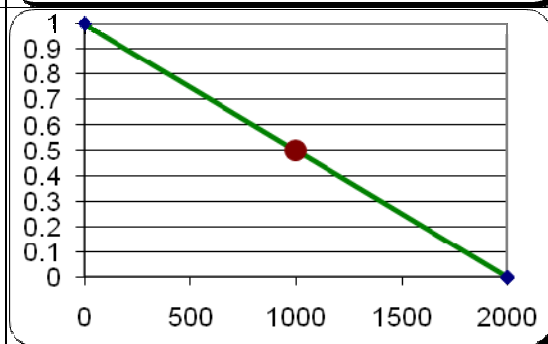
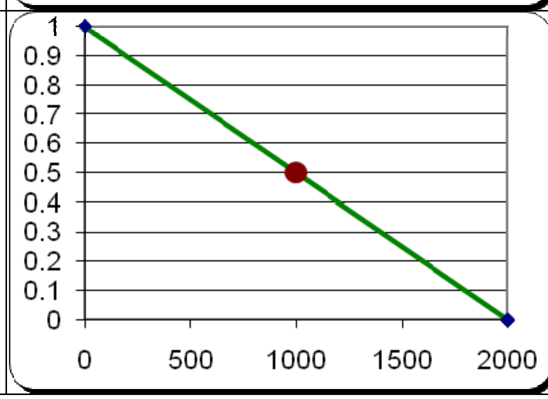
Sensitivity to Investment Behavior	Degree of Sensitivity	Categories	Constructed/ Direct	

Summary of the *Credible Model* Branch

Value	Measure	Measure Unit	Measure Type	Single Dimensional Value Function
Understandable	Degree of Comprehension	Categories	Constructed/ Direct	
Facility Type Life Cycles	# of Fac Types Used	Number	Natural/ Direct	
Use of Facility Factors (Type A)	# of Type A Factors Used	Number	Natural/ Direct	
Use of Facility Factors (Type B)	# of Type B Factors Used	Number	Natural/ Direct	

Use of Facility Factors (Type C)	# of Type C Factors Used	Number	Natural/ Direct	
Consistency of Budget Requests	Degree of Consistency	Categories	Constructed/ Direct	

Summary of the *Implementation* Branch

Value	Measure	Measure Unit	Measure Type	Single Dimensional Value Function
Effort of DoD	# of Hours req'd per year	Hours	Natural/ Direct	
Effort of PMs	# of Hours req'd per year	Hours	Natural/ Direct	
Effort of MAJCOM/ Bases	# of Hours req'd per year	Hours	Natural/ Direct	

Appendix C – Summary of Alternatives

ALTERNATIVE 1: Current Plant Value (CPV) (Barco, 94 & Ottoman, 99)		
TYPE: Formula Based	**Score based on Literature**	**Scored by DM Panel**
Description	EM	Score
This model is a formula based model that calculates the budget at a specific point in time. It can be calculated for a particular year into the future if needed, but becomes less accurate as the years progress. Market value is used.	Planning Horizon	2
This method is formula based and does not consider condition.	% of Method that is Condition Based	0
This method is formula based and does not consider life-cycle.	% of Method that is Life-Cycle Based	0
This method has received some support in literature as a valid approximation for recapitalization budgets, but is not recommended for large facility inventories.	Degree Supported in Lit/Practice	No
This method does not account for method of recapitalization.	Degree of Sensitivity	Low
The parameters of this method, in its basic form, include only an estimate of the current value of the facility. It is essentially the market value of the facility.	Degree of Comprehension	Med
N/A	# of Fac Types Used	0
N/A	# of Type A Factors Used	0
Market value	# of Type B Factors Used	1
N/A	# of Type C Factors Used	0
The budget requests should change from year to year, based on any improvements made to the facility and the prevailing market values.	Degree of Consistency	Med
This requires an estimation of the estimated man hours to use the model by the DoD.	# of Hours req'd per year (DoD)	R:600-1000 ML:800
This requires an estimation of the estimated man hours to use the model by the PMs.	# of Hours req'd per year (PMs)	R:600-1400 ML:1000
This requires an estimation of the estimated man hours to use the model by the Bases.	# of Hours req'd per year (Bases)	R:300-500 ML:400

ALTERNATIVE 2: Plant Replacement Value (PRV) (Barco, 94 & Ottoman, 99)		
TYPE: Formula Based	**Score based on Literature**	**Scored by DM Panel**
Description	EM	Score
This model is a formula based model that calculates the budget at a specific point in time. It can be calculated for a particular year into the future if needed, but becomes less accurate as the years progress.	Planning Horizon	5
This method is formula based and does not consider condition.	% of Method that is Condition Based	0
This method is formula based and does not consider life-cycle.	% of Method that is Life-Cycle Based	0
This method has received some support in literature as a valid approximation for recapitalization budgets.	Degree Supported in Lit/Practice	Yes
This method does not account for method of recapitalization.	Degree of Sensitivity	Low
The parameters of this method, in its basic form, include only an estimate of the cost to replace the facility.	Degree of Comprehension	High
N/A	# of Fac Types Used	0
Replacement cost and area cost factor are used in this model.	# of Type A Factors Used	2
N/A	# of Type B Factors Used	0
Facility size if often used in this calculation	# of Type C Factors Used	1
The budget requests should be highly consistent because they are based on replacement values. The only changes from year to year in replacement values should be from changes in factors.	Degree of Consistency	High
This requires an estimation of the estimated man hours to use the model by the DoD.	# of Hours req'd per year (DoD)	R:300-500 ML:400
This requires an estimation of the estimated man hours to use the model by the PMs.	# of Hours req'd per year (PMs)	R:700-900 ML:800
This requires an estimation of the estimated man hours to use the model by the Bases.	# of Hours req'd per year (Bases)	R:0-50 ML:20

ALTERNATIVE 3: Dergis-Sherman Formula		(Sherman & Dergis, 81)
TYPE: Formula Based	**Score based on Literature**	**Scored by DM Panel**
Description	EM	Score
This model is a formula based model that calculates the budget at a specific point in time. It can be calculated for a particular year into the future if needed, but becomes less accurate as the years progress. Market value is used.	Planning Horizon	2
This method is formula based and does not consider condition.	% of Method that is Condition Based	0
This method is slightly life-cycle based because it considers facility age as a parameter. However, the traditional life-cycle method of breaking the facility into sub-systems is not considered.	% of Method that is Life-Cycle Based	0
This method has received some support in literature as a valid approximation for recapitalization budgets, but because it is a variation of the CPV, it is not recommended for large facility inventories.	Degree Supported in Lit/Practice	No
This method does not account for method of recapitalization.	Degree of Sensitivity	Low
This model uses various constants which would require explanation to decision-makers.	Degree of Comprehension	Med
This model assumes an average facility age of 50 years for all types.	# of Fac Types Used	1
Facility Age	# of Type A Factors Used	1
Market Value of Facility	# of Type B Factors Used	1
N/A	# of Type C Factors Used	0
The budget requests should change from year to year in based on any improvements made to the facility and the prevailing market values.	Degree of Consistency	Med
This requires an estimation of the estimated man hours to use the model by the DoD.	# of Hours req'd per year (DoD)	R:600-1000 ML:800
This requires an estimation of the estimated man hours to use the model by the PMs.	# of Hours req'd per year (PMs)	R:800-1200 ML:1000
This requires an estimation of the estimated man hours to use the model by the Bases.	# of Hours req'd per year (Bases)	R:200-600 ML:400

ALTERNATIVE 4: Facilities Renewal – Phillips		(Ottoman, 99)
TYPE: Formula Based	**Score based on Literature**	**Scored by DM Panel**
Description	EM	Score
This model is a formula based model that calculates the budget at a specific point in time. It can be calculated for a particular year into the future if needed, but becomes less accurate as the years progress.	Planning Horizon	2
This method is formula based and does not consider condition.	% of Method that is Condition Based	0
This method is slightly life-cycle based because it breaks down facilities into systems and classifies them as 25 year or 50 year systems to establish the renewal allowances.	% of Method that is Life-Cycle Based	20
This method has received some support in literature as a valid approximation for recapitalization budgets, but because it is a variation of the CPV, it is not recommended for large facility inventories.	Degree Supported in Lit/Practice	No
This method does not account for method of recapitalization.	Degree of Sensitivity	Low
This model uses various constants which would require explanation to decision-makers.	Degree of Comprehension	Med
This model uses one facility type.	# of Fac Types Used	1
Facility Age	# of Type A Factors Used	1
Market Value of Facility	# of Type B Factors Used	1
N/A	# of Type C Factors Used	0
The budget requests should change from year to year in based on any improvements made to the facility and the prevailing market values.	Degree of Consistency	Med
This requires an estimation of the estimated man hours to use the model by the DoD.	# of Hours req'd per year (DoD)	R:600-1000 ML:800
This requires an estimation of the estimated man hours to use the model by the PMs.	# of Hours req'd per year (PMs)	R:800-1500 ML:1250
This requires an estimation of the estimated man hours to use the model by the Bases.	# of Hours req'd per year (Bases)	R:200-600 ML:400

ALTERNATIVE 5: Depreciation (Bar-Yosef 94, Fraumeni 97, Green 02, Lufkin 05, & Schmalz 95)		
TYPE: Formula Based	**Score based on Literature**	**Scored by DM Panel**
Description	EM	Score
This is a type of model that looks at the facility value over its life-span. The depreciation pattern and life span estimation will determine the budget amount, and the planner can look as far into the future as necessary for planning purposes.	Planning Horizon	30
This method is formula based and does not consider condition.	% of Method that is Condition Based	0
This method does not consider life-cycle sub-systems.	% of Method that is Life-Cycle Based	0
There is literature that supports and refutes each pattern of depreciation and its use for facility budgeting.	Degree Supported in Lit/Practice	No
The method in its basic form does not differentiate between methods of depreciation; however, specific variations could include them.	Degree of Sensitivity	Med
The basic premise of this model is to budget based off of depreciated building value.	Degree of Comprehension	Med
This method could include a number of facility types from an average value for all facilities to depreciating each facility independently. For the purposes of large facility inventories, a limited number is often used.	# of Fac Types Used	100
Facility Age and construction cost are the basic factors used in this model	# of Type A Factors Used	2
N/A	# of Type B Factors Used	0
Depreciation rates are used	# of Type C Factors Used	1
Budget requests should be predictable based on the depreciation patterns.	Degree of Consistency	High
This requires an estimation of the estimated man hours to use the model by the DoD.	# of Hours req'd per year (DoD)	R:800-1500 ML:1000
This requires an estimation of the estimated man hours to use the model by the PMs.	# of Hours req'd per year (PMs)	R:800-1500 ML:1200
This requires an estimation of the estimated man hours to use the model by the Bases.	# of Hours req'd per year (Bases)	R:0-100 ML:20

ALTERNATIVE 6: BUILDER		(Uzarski, 97)
TYPE: Life-Cycle & Condition Based	**Score based on Literature**	**Scored by DM Panel**
Description	EM	Score
BUILDER is a model that is life-cycle based and takes each facility sub system life span into account. Planners can look as far into the future as necessary for planning purposes.	Planning Horizon	30
This method uses predictive deterioration cost curves on facility subsystems combined with actual facility condition assessment data to determine the budget.	% of Method that is Condition Based	50
This method uses predictive deterioration cost curves on facility subsystems combined with actual facility condition assessment data to determine the budget.	% of Method that is Life-Cycle Based	50
Literature supports both life-cycle and condition based methods.	Degree Supported in Lit/Practice	Yes
This model does not differentiate between renovation and replacement.	Degree of Sensitivity	Low
This model is straight forward because it is based off condition and life cycles, however the numbers are put into software and may be difficult to explain the computations.	Degree of Comprehension	Med
This method looks at each facility individually and can be separated into as many facility types as required.	# of Fac Types Used	200
area cost factors, age factors	# of Type A Factors Used	2
none	# of Type B Factors Used	0
none	# of Type C Factors Used	0
Budget requests would vary greatly every year depending on the funding from previous years and the facility's age.	Degree of Consistency	Low
This requires an estimation of the estimated man hours to use the model by the DoD.	# of Hours req'd per year (DoD)	R:500-1500 ML:1000
This requires an estimation of the estimated man hours to use the model by the PMs.	# of Hours req'd per year (PMs)	R:500-1500 ML:1000
This requires an estimation of the estimated man hours to use the model by the Bases.	# of Hours req'd per year (Bases)	R:1500-2000 ML:1700

ALTERNATIVE 7: Renewal Factors		(Leslie, 97)
TYPE: Life-Cycle & Formula	Score based on Literature	Scored by DM Panel
Description	EM	Score
The Renewal factor model is a modified life-cycle based method that uses historical data to predict renewal cost factors using an equation. The planner can predict the future budgets by running the model for a particular year of the facility's life.	Planning Horizon	30
This method does not use condition.	% of Method that is Condition Based	0
This method uses life-cycle data per facility type to estimate renewal factors.	% of Method that is Life-Cycle Based	70
Literature has limited support this method and deems it as data intensive.	Degree Supported in Lit/Practice	No
This model does not differentiate between renovation and replacement.	Degree of Sensitivity	Low
This model has various factors based on algorithms in software and would be difficult to explain.	Degree of Comprehension	Low
This method looks at each facility individually and can be separated into as many facility types as required.	# of Fac Types Used	200
facility age, area cost factors	# of Type A Factors Used	2
construction cost, deferred maintenance	# of Type B Factors Used	2
facility size factors	# of Type C Factors Used	1
Budget requests would vary greatly every year depending on the funding from previous years and the facility's age	Degree of Consistency	low
This requires an estimation of the estimated man hours to use the model by the DoD.	# of Hours req'd per year (DoD)	R:400-700 ML:500
This requires an estimation of the estimated man hours to use the model by the PMs.	# of Hours req'd per year (PMs)	R:400-700 ML:500
This requires an estimation of the estimated man hours to use the model by the Bases.	# of Hours req'd per year (Bases)	R:500-1500 ML:1000

ALTERNATIVE 8: Applied Management Engineering (AME) (Ottoman, 99)		
TYPE: Condition & Life Cycle Based	**Score based on Literature**	**Scored by DM Panel**
Description	EM	Score
This model uses a 5 year planning horizon to predict facility system replacement schedules and budgets.	Planning Horizon	5
This method uses condition inspection data as well as facility life cycle data to estimate renewal costs.	% of Method that is Condition Based	50
This method uses condition inspection data as well as facility life cycle data to estimate renewal costs.	% of Method that is Life-Cycle Based	50
Condition assessment and life cycle methods are well supported in literature	Degree Supported in Lit/Practice	Yes
This model does not differentiate between renovation and replacement.	Degree of Sensitivity	Low
This model is based on physical data gathering and historical data and does not involve complicated equations or factors.	Degree of Comprehension	High
This method looks at each facility individually and can be separated into as many facility types as required.	# of Fac Types Used	200
facility age, area cost factor	# of Type A Factors Used	2
project backlog	# of Type B Factors Used	1
none	# of Type C Factors Used	0
Budget requests would vary greatly every year depending on the funding from previous years and the facility's age	Degree of Consistency	Low
This requires an estimation of the estimated man hours to use the model by the DoD.	# of Hours req'd per year (DoD)	R:300-800 ML:500
This requires an estimation of the estimated man hours to use the model by the PMs.	# of Hours req'd per year (PMs)	R:300-800 ML:500
This requires an estimation of the estimated man hours to use the model by the Bases.	# of Hours req'd per year (Bases)	R:1000-2000 ML:1500

ALTERNATIVE 9: Facilities Recapitalization Model (FRM) (Barco, 94)		
TYPE: Formula Based	**Score based on Literature**	**Scored by DM Panel**
Description	EM	Score
This model is a formula based model that calculates the budget at a specific point in time. It can be calculated for a particular year into the future if needed, but becomes less accurate as the years progress.	Planning Horizon	5
This method does not consider condition.	% of Method that is Condition Based	0
This method does not consider life-cycle.	% of Method that is Life-Cycle Based	0
This model uses PRV as the basis for calculation, which has been found to be a good approximation for large facility inventories.	Degree Supported in Lit/Practice	Yes
This model does not differentiate between renovation and replacement.	Degree of Sensitivity	Low
This model is in use currently and has not received the expected amount of support.	Degree of Comprehension	Med
This method uses an average facility life span of 67 years for all facilities.	# of Fac Types Used	1
area cost factors	# of Type A Factors Used	1
construction cost factor, historic adjustment factor, planning & Design factor	# of Type B Factors Used	3
facility size factor	# of Type C Factors Used	1
Budget requests should be predictable based on the PRV formulas and would only vary as the factors changed.	Degree of Consistency	High
This requires an estimation of the estimated man hours to use the model by the DoD.	# of Hours req'd per year (DoD)	R:50-200 ML:100
This requires an estimation of the estimated man hours to use the model by the PMs.	# of Hours req'd per year (PMs)	R:100-300 ML:200
This requires an estimation of the estimated man hours to use the model by the Bases.	# of Hours req'd per year (Bases)	R:5-30 ML:20

ALTERNATIVE 10: Facilities Modernization Model (FMM) (Barco, 94)			
TYPE: Formula Based		**Score based on Literature**	**Scored by DM Panel**

Description	EM	Score
This model is a formula based model that calculates the budget based off of a straight-line depreciation pattern and the PRV. Like the FRM, this model can be calculated for future years but loses accuracy the further into the future the prediction goes.	Planning Horizon	30
This method does not consider condition.	%Condition Based	0
This method does not consider life-cycle.	% of Method that is Life-Cycle Based	0
This model uses a straight-line depreciation pattern which has not been conclusively determined to be an accurate depreciation method for facilities.	Degree Supported in Lit/Practice	No
This model uses an average between renovation and replacement costs.	Degree of Sensitivity	Med
This model has a straight forward metric, but also contains some complicated factors that could be difficult to explain.	Degree of Comprehension	Med
This method breaks down facilities into life cycles based on facility codes	# of Fac Types Used	70
area cost factors	# of Type A Factors Used	2
construction cost factor, historic adjustment factor, planning & Design factor	# of Type B Factors Used	3
facility size factor, depreciation factors	# of Type C Factors Used	2
Budget requests would be predictable based on the depreciation slopes and would only vary according to the various changes in factors.	Degree of Consistency	High
This requires an estimation of the estimated man hours to use the model by the DoD.	# of Hours req'd per year (DoD)	R:50-200 ML:150
This requires an estimation of the estimated man hours to use the model by the PMs.	# of Hours req'd per year (PMs)	R:200-300 ML:250
This requires an estimation of the estimated man hours to use the model by the Bases.	# of Hours req'd per year (Bases)	R:10-90 ML:50

ALTERNATIVE 11: Do Nothing (Bottom-Up Only) (Barco, 94)		
TYPE: N/A	Score based on Literature	Scored by DM Panel
Description	EM	Score
This model could only have a 5 year planning horizon based on MILCON planning timelines for facility replacements and major renovations.	Planning Horizon	5
This method does not consider condition.	% of Method that is Condition Based	0
This method does not consider life-cycle.	% of Method that is Life-Cycle Based	0
This model would use budget requests from the bases and MAJCOMS as the prediction tool, which is not a concept supported in literature.	Degree Supported in Lit/Practice	No
This method would allot funding based on the specific projects therefore renovation and replacement would be specified.	Degree of Sensitivity	High
This method would be easily understood because it is justified by project description.	Degree of Comprehension	High
N/A	# of Fac Types Used	0
N/A	# of Type A Factors Used	0
N/A	# of Type B Factors Used	0
N/A	# of Type C Factors Used	0
Budget requests would vary widely from year to year.	Degree of Consistency	Low
This requires an estimation of the estimated man hours to use the model by the DoD.	# of Hours req'd per year (DoD)	R:10-50 ML:20
This requires an estimation of the estimated man hours to use the model by the PMs.	# of Hours req'd per year (PMs)	R:20-100 ML:50
This requires an estimation of the estimated man hours to use the model by the Bases.	# of Hours req'd per year (Bases)	R:50-700 ML:500

ALTERNATIVE 12: Q-Rating System			(Barco, 94)
TYPE: Condition Assessment		**Score based on Literature**	**Scored by DM Panel**

Description	EM	Score
This model could only have a 5 year planning horizon based on MILCON planning timelines for facility replacements and major renovations.	Planning Horizon	5
This method would be mostly based off of condition.	% of Method that is Condition Based	75
This method does not consider life-cycle.	% of Method that is Life-Cycle Based	0
This model would use a system of rating facilities based on condition and facility priority, which is supported in literature.	Degree Supported in Lit/Practice	Yes
This method would allot funding based on the specific projects therefore renovation and replacement would be specified.	Degree of Sensitivity	High
This method would be easily understood because it is justified by project description and condition	Degree of Comprehension	High
This method looks at each facility individually and can be separated into as many facility types as required.	# of Fac Types Used	200
facility priority, area cost factor	# of Type A Factors Used	2
N/A	# of Type B Factors Used	0
N/A	# of Type C Factors Used	0
Budget requests would vary widely from year to year.	Degree of Consistency	Low
This requires an estimation of the estimated man hours to use the model by the DoD.	# of Hours req'd per year (DoD)	R:10-50 ML:20
This requires an estimation of the estimated man hours to use the model by the PMs.	# of Hours req'd per year (PMs)	R:20-100 ML:50
This requires an estimation of the estimated man hours to use the model by the Bases.	# of Hours req'd per year (Bases)	R:1500-2000 ML:1700

ALTERNATIVE 13: Alt FRM		(Barco, 94)
TYPE: Formula Based	**Score based on Literature**	**Scored by DM Panel**
Description	EM	Score
This model is a formula based model that calculates the budget at a specific point in time. It can be calculated for a particular year into the future if needed, but becomes less accurate as the years progress.	Planning Horizon	5
This method does not consider condition.	% of Method that is Condition Based	0
This method does not consider life-cycle.	% of Method that is Life-Cycle Based	0
This model uses PRV as the basis for calculation, which has been found to be a good approximation for large facility inventories.	Degree Supported in Lit/Practice	Yes
This model does not differentiate between renovation and replacement.	Degree of Sensitivity	Low
This model is in use currently and has not received the expected amount of support.	Degree of Comprehension	Med
This variation of FRM would use established facility lives based on the facility codes.	# of Fac Types Used	124
area cost factors	# of Type A Factors Used	1
construction cost factor, historic adjustment factor, planning & Design factor	# of Type B Factors Used	3
facility size factor	# of Type C Factors Used	1
Budget requests should be predictable based on the PRV formulas and would only vary as the factors changed.	Degree of Consistency	High
This requires an estimation of the estimated man hours to use the model by the DoD.	# of Hours req'd per year (DoD)	R:100-300 ML:150
This requires an estimation of the estimated man hours to use the model by the PMs.	# of Hours req'd per year (PMs)	R:200-400 ML:250
This requires an estimation of the estimated man hours to use the model by the Bases.	# of Hours req'd per year (Bases)	R:30-70 ML:50

ALTERNATIVE 14: ALT FMM		(Barco, 94)
TYPE: Formula Based	Score based on Literature	Scored by DM Panel

Description	EM	Score
This model is a formula based model that calculates the budget based off of a straight-line depreciation pattern and the PRV. Like the FRM, this model can be calculated for future years but loses accuracy the further into the future the prediction goes.	Planning Horizon	30
This method does not consider condition.	% of Method that is Condition Based	0
This method does not consider life-cycle.	% of Method that is Life-Cycle Based	0
This version of the FMM would be updated with the depreciation patterns that were best supported in literature.	Degree Supported in Lit/Practice	Yes
This model uses an average between renovation and replacement costs.	Degree of Sensitivity	Med
This model has a straight forward metric, but also contains some complicated factors that could be difficult to explain.	Degree of Comprehension	Med
This method breaks down facilities into life cycles based on facility codes	# of Fac Types Used	70
area cost factors	# of Type A Factors Used	2
construction cost factor, historic adjustment factor, planning & Design factor	# of Type B Factors Used	3
facility size factor, depreciation factors	# of Type C Factors Used	2
Budget requests would be predictable based on the depreciation slopes and would only vary according to the various changes in factors.	Degree of Consistency	High
This requires an estimation of the estimated man hours to use the model by the DoD.	# of Hours req'd per year (DoD)	R:50-200 ML:150
This requires an estimation of the estimated man hours to use the model by the PMs.	# of Hours req'd per year (PMs)	R:200-300 ML:250
This requires an estimation of the estimated man hours to use the model by the Bases.	# of Hours req'd per year (Bases)	R:10-90 ML:50

ALTERNATIVE 15: H-Model			
TYPE: Combination		**Score based on Literature**	**Scored by DM Panel**
Description		EM	Score
The life-cycle predictions engrained in this model would allow for max planning horizon.		Planning Horizon	30
This method would ensure that condition was assessed and implemented into the decision process.		% of Method that is Condition Based	50
This method would contain life-cycle historical data based on existing systems.		% of Method that is Life-Cycle Based	25
This model would ensure that all data and methods used are supported in literature.		Degree Supported in Lit/Practice	Yes
This model would separate the estimates based on renovation and replacement.		Degree of Sensitivity	High
This model would have straight forward parameters and metrics		Degree of Comprehension	High
This method breaks down facilities into life cycles based on facility codes		# of Fac Types Used	200
area cost factors, replacement costs, facility priority, age		# of Type A Factors Used	4
climate, construction costs		# of Type B Factors Used	2
none		# of Type C Factors Used	0
Due to all the inputs into this model, the consistency is likely to vary more than the standard inflation rates.		Degree of Consistency	Med
This requires an estimation of the estimated man hours to use the model by the DoD.		# of Hours req'd per year (DoD)	R:500-1500 ML:1000
This requires an estimation of the estimated man hours to use the model by the PMs.		# of Hours req'd per year (PMs)	R:500-1500 ML:1000
This requires an estimation of the estimated man hours to use the model by the Bases.		# of Hours req'd per year (Bases)	R:1500-2000 ML:1700

Appendix D – Raw Score Data, Value, and Expected Value Calculations

Raw Score Data for EMs Planning Horizon - Sensitivity

	Planning Horiz				% Condit				% Life-Cycle				Empirical Support				Sensitivity			
Alternative	Prob.	Score (X)	Weight	Value	P	X	W	V	P	X	W	V	.	X	W	V	P	X	W	V
CPV	1	2	0.167	0.333	1	0	0.044	0	1	0	0.039	0	1	No	0.028	0	1	Low	0.056	0
PRV	1	5	0.167	0.75	1	0	0.044	0	1	0	0.039	0	1	Yes	0.028	1	1	Low	0.056	0
Dergis-Sherman	1	2	0.167	0.333	1	0	0.044	0	1	0	0.039	0	1	No	0.028	0	1	Low	0.056	0
Fac. Renewal	1	2	0.167	0.333	1	0	0.044	0	1	20	0.039	0.2	1	No	0.028	0	1	Low	0.056	0
Depreciation	1	30	0.167	1	1	0	0.044	0	1	0	0.039	0	1	No	0.028	0	1	Med	0.056	0.67
BUILDER	1	30	0.167	1	1	50	0.044	0.5	1	50	0.039	0.5	1	Yes	0.028	1	1	Low	0.056	0
Renewal Fact.	1	30	0.167	1	1	0	0.044	0	1	70	0.039	0.7	1	No	0.028	0	1	Low	0.056	0
AME	1	5	0.167	0.75	1	50	0.044	0.5	1	50	0.039	0.5	1	Yes	0.028	1	1	Low	0.056	0
FRM	1	5	0.167	0.75	1	0	0.044	0	1	0	0.039	0	1	Yes	0.028	1	1	Low	0.056	0
FMM	1	30	0.167	1	1	0	0.044	0	1	0	0.039	0	1	No	0.028	0	1	Med	0.056	0.67
Bottom Up	1	5	0.167	0.75	1	0	0.044	0	1	0	0.039	0	1	No	0.028	0	1	High	0.056	1
Q Factors	1	5	0.167	0.75	1	75	0.044	0.75	1	0	0.039	0	1	Yes	0.028	1	1	High	0.056	1
Alt FRM	1	5	0.167	0.75	1	0	0.044	0	1	0	0.039	0	1	Yes	0.028	1	1	Low	0.056	0
Alt FMM	1	30	0.167	1	1	0	0.044	0	1	0	0.039	0	1	Yes	0.028	1	1	Med	0.056	0.67
H-Model	1	30	0.167	1	1	50	0.044	0.5	1	25	0.039	0.25	1	Yes	0.028	1	1	High	0.056	1

Raw Score Data for EMs Comprehension - Consistency

Alternative	Comprehension				# Fac Tp				# Tp A				# Tp B				# Tp C				Consistency			
	P	X	W	V	P	X	W	V	P	X	W	V	P	X	W	V	P	X	W	V	P	X	W	V
CPV	1	Med	0.222	0.67	1	0	0.1	0	1	0	0.033	0	1	1	0.023	0.167	1	0	0.010	0	1	Med	0.167	0.67
PRV	1	High	0.222	1	1	0	0.1	0	1	2	0.033	0.4	1	0	0.023	0.000	1	1	0.010	0.333	1	High	0.167	1
Dergis-Sherman	1	Med	0.222	0.67	1	1	0.1	0.01	1	1	0.033	0.2	1	1	0.023	0.167	1	0	0.010	0.000	1	Med	0.167	0.67
Fac. Renewal	1	Med	0.222	0.67	1	1	0.1	0.01	1	1	0.033	0.2	1	1	0.023	0.167	1	0	0.010	0.000	1	Med	0.167	0.67
Depreciation	1	Med	0.222	0.67	1	100	0.1	0.5	1	2	0.033	0.4	1	0	0.023	0.000	1	1	0.010	0.333	1	High	0.167	1
BUILDER	1	Med	0.222	0.67	1	200	0.1	1	1	2	0.033	0.4	1	0	0.023	0.000	1	0	0.010	0.000	1	Low	0.167	0
Renewal Fact.	1	Low	0.222	0	1	200	0.1	1	1	2	0.033	0.4	1	2	0.023	0.333	1	1	0.010	0.333	1	Low	0.167	0
AME	1	High	0.222	1	1	200	0.1	1	1	2	0.033	0.4	1	1	0.023	0.167	1	0	0.010	0.000	1	Low	0.167	0
FRM	1	Med	0.222	0.67	1	1	0.1	0.01	1	1	0.033	0.2	1	3	0.023	0.500	1	1	0.010	0.333	1	High	0.167	1
FMM	1	Med	0.222	0.67	1	70	0.1	0.35	1	2	0.033	0.4	1	3	0.023	0.500	1	2	0.010	0.667	1	High	0.167	1
Bottom Up	1	High	0.222	1	1	0	0.1	0	1	0	0.033	0	1	0	0.023	0.000	1	0	0.010	0.000	1	Low	0.167	0
Q Factors	1	High	0.222	1	1	200	0.1	1	1	2	0.033	0.4	1	0	0.023	0.000	1	0	0.010	0.000	1	Low	0.167	0
Alt FRM	1	Med	0.222	0.67	1	124	0.1	0.62	1	1	0.033	0.2	1	3	0.023	0.500	1	1	0.010	0.333	1	High	0.167	1
Alt FMM	1	Med	0.222	0.67	1	70	0.1	0.35	1	2	0.033	0.4	1	3	0.023	0.500	1	2	0.010	0.667	1	High	0.167	1
H-Model	1	High	0.222	1	1	200	0.1	1	1	4	0.033	0.8	1	2	0.023	0.333	1	0	0.010	0.000	1	Med	0.167	0.67

Raw Score Data for DoD Hrs – Base Hrs, Value and Expected Value Calculations

Alternative	Hrs DoD				Hrs PM				Hrs Bases				VALUE	Expected Value
	P	X	W	V	P	X	W	V	P	X	W	V		
CPV	0	600	0.0185	0.7	0	600	0.037	0.7	0	300	0.0555	0.85		
	1	800	0.0185	0.6	1	1000	0.037	0.5	1	400	0.0555	0.8	0.394	0.394
	0	1000	0.0185	0.5	0	1400	0.037	0.3	0	500	0.0555	0.75		
PRV	0	300	0.0185	0.85	0	700	0.037	0.65	0	0	0.0555	1		
	1	400	0.0185	0.8	1	800	0.037	0.6	1	20	0.0555	0.99	0.650	0.650
	0	500	0.0185	0.75	0	900	0.037	0.55	0	50	0.0555	0.975		
Dergis Sherman	0	600	0.0185	0.7	0	800	0.037	0.6	0	200	0.0555	0.9		
	1	800	0.0185	0.6	1	1000	0.037	0.5	1	400	0.0555	0.8	0.401	0.401
	0	1000	0.0185	0.5	0	1200	0.037	0.4	0	600	0.0555	0.7		
Fac. Renewal	0	600	0.0185	0.7	0	800	0.037	0.6	0	200	0.0555	0.9		
	1	800	0.0185	0.6	1	1250	0.037	0.375	1	400	0.0555	0.8	0.404	0.405
	0	1000	0.0185	0.5	0	1500	0.037	0.25	0	600	0.0555	0.7		
Depreciation	0	800	0.0185	0.6	0	800	0.037	0.6	0	0	0.0555	1		
	1	1000	0.0185	0.5	1	1200	0.037	0.4	1	20	0.0555	0.99	0.665	0.665
	0	1500	0.0185	0.25	0	1500	0.037	0.25	0	100	0.0555	0.95		
BUILDER	0	500	0.0185	0.75	0	500	0.037	0.75	0	1500	0.0555	0.25		
	1	1000	0.0185	0.5	1	1000	0.037	0.5	1	1700	0.0555	0.15	0.534	0.534
	0	1500	0.0185	0.25	0	1500	0.037	0.25	0	2000	0.0555	0		
Renewal Fact.	0	400	0.0185	0.8	0	400	0.037	0.8	0	500	0.0555	0.75		
	1	500	0.0185	0.75	1	500	0.037	0.75	1	1000	0.0555	0.5	0.388	0.387
	0	700	0.0185	0.65	0	700	0.037	0.65	0	1500	0.0555	0.25		
AME	0	300	0.0185	0.85	0	300	0.037	0.85	0	1000	0.0555	0.5		
	1	500	0.0185	0.75	1	500	0.037	0.75	1	1500	0.0555	0.25	0.589	0.589
	0	800	0.0185	0.6	0	800	0.037	0.6	0	2000	0.0555	0		
FRM	0	50	0.0185	0.975	0	100	0.037	0.95	0	5	0.0555	0.998		
	1	100	0.0185	0.95	1	200	0.037	0.9	1	20	0.0555	0.99	0.596	0.596
	0	200	0.0185	0.9	0	300	0.037	0.85	0	30	0.0555	0.985		
FMM	0	50	0.0185	0.975	0	200	0.037	0.9	0	10	0.0555	0.995		
	1	150	0.0185	0.925	1	250	0.037	0.875	1	50	0.0555	0.975	0.690	0.690
	0	200	0.0185	0.9	0	300	0.037	0.85	0	90	0.0555	0.955		
Bottom Up	0	10	0.0185	0.995	0	20	0.037	0.99	0	50	0.0555	0.975		
	1	20	0.0185	0.99	1	50	0.037	0.975	1	500	0.0555	0.75	0.499	0.500
	0	50	0.0185	0.975	0	100	0.037	0.95	0	700	0.0555	0.65		
Q Factors	0	10	0.0185	0.995	0	20	0.037	0.99	0	1500	0.0555	0.25		
	1	20	0.0185	0.99	1	50	0.037	0.975	1	1700	0.0555	0.15	0.640	0.639
	0	50	0.0185	0.975	0	100	0.037	0.95	0	2000	0.0555	0		
Alt FRM	0	100	0.0185	0.95	0	200	0.037	0.9	0	30	0.0555	0.985		
	1	150	0.0185	0.925	1	250	0.037	0.875	1	50	0.0555	0.975	0.656	0.655
	0	300	0.0185	0.85	0	400	0.037	0.8	0	70	0.0555	0.965		
Alt FMM	0	50	0.0185	0.975	0	200	0.037	0.9	0	10	0.0555	0.995		
	1	150	0.0185	0.925	1	250	0.037	0.875	1	50	0.0555	0.975	0.718	0.718
	0	200	0.0185	0.9	0	300	0.037	0.85	0	90	0.0555	0.955		
H-Model	0	500	0.0185	0.75	0	500	0.037	0.75	0	1500	0.0555	0.25		
	1	1000	0.0185	0.5	1	1000	0.037	0.5	1	1700	0.0555	0.15	0.787	0.786
	0	1500	0.0185	0.25	0	1500	0.037	0.25	0	2000	0.0555	0		

Appendix E - Expected Utility Raw Data

E(U) Data for All Alternatives: EMs Planning Horizon - # Facility Types

	Planning Horizon			% Condition			% Life-Cycle			Emp. Support			Sensitivity			Comprehension		
Alternative	**Weight**	**Score**	**Value**	**W**	**X**	**V**	**W**	**X**	**V**	**W**	**X**	**V**	**W**	**X**	**V**	**W**	**X**	**V**
CPV	0.167	2	0.333	0.044	0	0	0.039	0	0	0.028	No	0	0.056	Low	0	0.222	Med	0.67
PRV	0.167	5	0.75	0.044	0	0	0.039	0	0	0.028	Yes	1	0.056	Low	0	0.222	High	1
Dergis Sher.	0.167	2	0.333	0.044	0	0	0.039	0	0	0.028	No	0	0.056	Low	0	0.222	Med	0.67
Fac. Renewal	0.167	2	0.333	0.044	0	0	0.039	20	0.2	0.028	No	0	0.056	Low	0	0.222	Med	0.67
Depreciation	0.167	30	1.000	0.044	0	0	0.039	0	0	0.028	No	0	0.056	Med	0.67	0.222	High	1
BUILDER	0.167	30	1.000	0.044	50	0.5	0.039	50	0.5	0.028	Yes	1	0.056	Low	0	0.222	Med	0.67
Renewal Fact.	0.167	30	1.000	0.044	0	0	0.039	70	0.7	0.028	No	0	0.056	Low	0	0.222	Low	0
AME	0.167	5	0.75	0.044	50	0.5	0.039	50	0.5	0.028	Yes	1	0.056	Low	0	0.222	High	1
FRM	0.167	5	0.75	0.044	0	0	0.039	0	0	0.028	Yes	1	0.056	Low	0	0.222	Med	0.67
FMM	0.167	30	1.000	0.044	0	0	0.039	0	0	0.028	No	0	0.056	Med	0.67	0.222	Med	0.67
Bottom Up	0.167	5	0.75	0.044	0	0	0.039	0	0	0.028	No	0	0.056	High	1	0.222	High	1
Q-Factors	0.167	5	0.75	0.044	75	0.75	0.039	0	0	0.028	Yes	1	0.056	High	1	0.222	High	1
Alt FRM	0.167	5	0.75	0.044	0	0	0.039	0	0	0.028	Yes	1	0.056	Low	0	0.222	Med	0.67
Alt FMM	0.167	30	1.000	0.044	0	0	0.039	0	0	0.028	Yes	1	0.056	Med	0.67	0.222	Med	0.67
H-Model	0.167	30	1.000	0.044	50	0.5	0.039	25	0.25	0.028	Yes	1	0.056	High	1	0.222	High	1

E(U) Data for All Alternatives: EMs Type A - Consistency

Alternative	# Fac Types			Type A			Type B			Type C			Consistency		
	W	**X**	**V**	W	X	V	W	X	V	W	X	V	W	X	V
CPV	0.100	0	0	0.033	0	0	0.023	1	0.167	0.010	0	0	0.167	Med	0.67
PRV	0.056	0	0	0.033	2	0.4	0.023	0	0	0.010	1	0.333	0.167	High	1
Dergis Sherman	0.056	1	0.005	0.033	1	0.2	0.023	1	0.167	0.010	0	0	0.167	Med	0.67
Facilities Renewal	0.056	1	0.005	0.033	1	0.2	0.023	1	0.167	0.010	0	0	0.167	Med	0.67
Depreciation	0.056	100	0.5	0.033	2	0.4	0.023	0	0	0.010	1	0.333	0.17	High	1
BUILDER	0.056	200	1	0.033	2	0.4	0.023	0	0	0.01	0	0	0.167	Low	0
Renewal Factors	0.056	200	1	0.033	2	0.4	0.023	2	0.333	0.010	1	0.333	0.17	Low	0
AME	0.056	200	1	0.033	2	0.4	0.023	1	0.167	0.010	0	0	0.167	Low	0
FRM	0.056	1	0.005	0.033	1	0.2	0.023	3	0.5	0.010	1	0.333	0.167	High	1
FMM	0.056	70	0.35	0.033	2	0.4	0.023	3	0.5	0.010	2	0.667	0.167	High	1
Bottom Up	0.056	0	0	0.033	0	0	0.023	0	0	0.010	0	0	0.167	Low	0
Q-Factors	0.056	200	1	0.033	2	0.4	0.023	0	0	0.010	0	0	0.167	Low	0
Alt FRM	0.056	124	0.62	0.033	1	0.2	0.023	3	0.5	0.010	1	0.333	0.167	High	1
Alt FMM	0.056	70	0.35	0.033	2	0.4	0.023	3	0.5	0.010	2	0.667	0.167	High	1
H-Model	0.056	200	1	0.033	4	0.8	0.023	2	0.333	0.010	0	0	0.167	Med	0.67

E(U) Data for CPV: DoD – E(U) Calculations

R=	0.269	DoD				PM				Base				Total	Value of	Utility of	EU of
Alternative		Prob.	Weight	Score (X)	Value	P	W	X	V	P	W	X	V	Prob.	Outcome	Outcome	Alt
CPV	Outcome 1	0.185	0.01854	600	0.7	0.185	0.03696	600	0.7	0.185	0.0555	300	0.85	0.0063	0.4061	0.7984	
	Outcome 2	0.185	0.01854	600	0.7	0.185	0.03696	600	0.7	0.63	0.0555	400	0.8	0.0216	0.4034	0.7961	
	Outcome 3	0.185	0.01854	600	0.7	0.185	0.03696	600	0.7	0.185	0.0555	500	0.75	0.0063	0.4006	0.7937	
	Outcome 4	0.185	0.01854	600	0.7	0.63	0.03696	1000	0.5	0.185	0.0555	300	0.85	0.0216	0.3987	0.7921	
	Outcome 5	0.185	0.01854	600	0.7	0.63	0.03696	1000	0.5	0.63	0.0555	400	0.8	0.0734	0.3960	0.7897	
	Outcome 6	0.185	0.01854	600	0.7	0.63	0.03696	1000	0.5	0.185	0.0555	500	0.75	0.0216	0.3932	0.7873	
	Outcome 7	0.185	0.01854	600	0.7	0.185	0.03696	1400	0.3	0.185	0.0555	300	0.85	0.0063	0.3913	0.7856	
	Outcome 8	0.185	0.01854	600	0.7	0.185	0.03696	1400	0.3	0.63	0.0555	400	0.8	0.0216	0.3886	0.7832	
	Outcome 9	0.185	0.01854	600	0.7	0.185	0.03696	1400	0.3	0.185	0.0555	500	0.75	0.0063	0.3858	0.7807	
	Outcome 10	0.63	0.01854	800	0.6	0.185	0.03696	600	0.7	0.185	0.0555	300	0.85	0.0216	0.4043	0.7969	
	Outcome 11	0.63	0.01854	800	0.6	0.185	0.03696	600	0.7	0.63	0.0555	400	0.8	0.0734	0.4015	0.7945	
	Outcome 12	0.63	0.01854	800	0.6	0.185	0.03696	600	0.7	0.185	0.0555	500	0.75	0.0216	0.3987	0.7921	
	Outcome 13	0.63	0.01854	800	0.6	0.63	0.03696	1000	0.5	0.185	0.0555	300	0.85	0.0734	0.3969	0.7905	
	Outcome 14	0.63	0.01854	800	0.6	0.63	0.03696	1000	0.5	0.63	0.0555	400	0.8	0.2500	0.3941	0.7881	0.7880
	Outcome 15	0.63	0.01854	800	0.6	0.63	0.03696	1000	0.5	0.185	0.0555	500	0.75	0.0734	0.3913	0.7856	
	Outcome 16	0.63	0.01854	800	0.6	0.185	0.03696	1400	0.3	0.185	0.0555	300	0.85	0.0216	0.3895	0.7840	
	Outcome 17	0.63	0.01854	800	0.6	0.185	0.03696	1400	0.3	0.63	0.0555	400	0.8	0.0734	0.3867	0.7815	
	Outcome 18	0.63	0.01854	800	0.6	0.185	0.03696	1400	0.3	0.185	0.0555	500	0.75	0.0216	0.3839	0.7790	
	Outcome 19	0.185	0.01854	1000	0.5	0.185	0.03696	600	0.7	0.185	0.0555	300	0.85	0.0063	0.4024	0.7953	
	Outcome 20	0.185	0.01854	1000	0.5	0.185	0.03696	600	0.7	0.63	0.0555	400	0.8	0.0216	0.3996	0.7929	
	Outcome 21	0.185	0.01854	1000	0.5	0.185	0.03696	600	0.7	0.185	0.0555	500	0.75	0.0063	0.3969	0.7905	
	Outcome 22	0.185	0.01854	1000	0.5	0.63	0.03696	1000	0.5	0.185	0.0555	300	0.85	0.0216	0.3950	0.7889	
	Outcome 23	0.185	0.01854	1000	0.5	0.63	0.03696	1000	0.5	0.63	0.0555	400	0.8	0.0734	0.3923	0.7864	
	Outcome 24	0.185	0.01854	1000	0.5	0.63	0.03696	1000	0.5	0.185	0.0555	500	0.75	0.0216	0.3895	0.7840	
	Outcome 25	0.185	0.01854	1000	0.5	0.185	0.03696	1400	0.3	0.185	0.0555	300	0.85	0.0063	0.3876	0.7823	

	Outcome 26	0.185	0.01854	1000	0.5	0.185	0.03696	1400	0.3	0.63	0.0555	400	0.8	0.0216	0.3849	0.7798	
	Outcome 27	0.185	0.01854	1000	0.5	0.185	0.03696	1400	0.3	0.185	0.0555	500	0.75	0.0063	0.3821	0.7773	

E(U) Data for PRV: DoD – E(U) Calculations

R=	**0.269**	**DoD**				**PM**				**Base**				**Total**	**Value of**	**Utility of**	**EU of**
Alternative		**Prob.**	**Weight**	**Score (X)**	**Value**	**P**	**W**	**X**	**V**	**P**	**W**	**X**	**V**	**Prob.**	**Outcome**	**Outcome**	**Alt**
PRV	Outcome 1	0.185	0.01854	300	0.85	0.185	0.03696	700	0.65	0.185	0.0555	0	1	0.0063	0.6538	0.9347	
	Outcome 2	0.185	0.01854	300	0.85	0.185	0.03696	700	0.65	0.63	0.0555	20	0.99	0.0216	0.6532	0.9345	
	Outcome 3	0.185	0.01854	300	0.85	0.185	0.03696	700	0.65	0.185	0.0555	50	0.975	0.0063	0.6524	0.9342	
	Outcome 4	0.185	0.01854	300	0.85	0.63	0.03696	800	0.6	0.185	0.0555	0	1	0.0216	0.6519	0.9341	
	Outcome 5	0.185	0.01854	300	0.85	0.63	0.03696	800	0.6	0.63	0.0555	20	0.99	0.0734	0.6514	0.9339	
	Outcome 6	0.185	0.01854	300	0.85	0.63	0.03696	800	0.6	0.185	0.0555	50	0.975	0.0216	0.6505	0.9336	
	Outcome 7	0.185	0.01854	300	0.85	0.185	0.03696	900	0.55	0.185	0.0555	0	1	0.0063	0.6501	0.9335	
	Outcome 8	0.185	0.01854	300	0.85	0.185	0.03696	900	0.55	0.63	0.0555	20	0.99	0.0216	0.6495	0.9333	
	Outcome 9	0.185	0.01854	300	0.85	0.185	0.03696	900	0.55	0.185	0.0555	50	0.975	0.0063	0.6487	0.9330	
	Outcome 10	0.63	0.01854	400	0.8	0.185	0.03696	700	0.65	0.185	0.0555	0	1	0.0216	0.6528	0.9344	
	Outcome 11	0.63	0.01854	400	0.8	0.185	0.03696	700	0.65	0.63	0.0555	20	0.99	0.0734	0.6523	0.9342	
	Outcome 12	0.63	0.01854	400	0.8	0.185	0.03696	700	0.65	0.185	0.0555	50	0.975	0.0216	0.6514	0.9339	
	Outcome 13	0.63	0.01854	400	0.8	0.63	0.03696	800	0.6	0.185	0.0555	0	1	0.0734	0.6510	0.9338	
	Outcome 14	0.63	0.01854	400	0.8	0.63	0.03696	800	0.6	0.63	0.0555	20	0.99	0.2500	0.6504	0.9336	0.9336
	Outcome 15	0.63	0.01854	400	0.8	0.63	0.03696	800	0.6	0.185	0.0555	50	0.975	0.0734	0.6496	0.9333	
	Outcome 16	0.63	0.01854	400	0.8	0.185	0.03696	900	0.55	0.185	0.0555	0	1	0.0216	0.6491	0.9331	
	Outcome 17	0.63	0.01854	400	0.8	0.185	0.03696	900	0.55	0.63	0.0555	20	0.99	0.0734	0.6486	0.9329	
	Outcome 18	0.63	0.01854	400	0.8	0.185	0.03696	900	0.55	0.185	0.0555	50	0.975	0.0216	0.6477	0.9327	
	Outcome 19	0.185	0.01854	500	0.75	0.185	0.03696	700	0.65	0.185	0.0555	0	1	0.0063	0.6519	0.9341	
	Outcome 20	0.185	0.01854	500	0.75	0.185	0.03696	700	0.65	0.63	0.0555	20	0.99	0.0216	0.6513	0.9339	
	Outcome 21	0.185	0.01854	500	0.75	0.185	0.03696	700	0.65	0.185	0.0555	50	0.975	0.0063	0.6505	0.9336	
	Outcome 22	0.185	0.01854	500	0.75	0.63	0.03696	800	0.6	0.185	0.0555	0	1	0.0216	0.6501	0.9335	
	Outcome 23	0.185	0.01854	500	0.75	0.63	0.03696	800	0.6	0.63	0.0555	20	0.99	0.0734	0.6495	0.9333	
	Outcome 24	0.185	0.01854	500	0.75	0.63	0.03696	800	0.6	0.185	0.0555	50	0.975	0.0216	0.6487	0.9330	
	Outcome 25	0.185	0.01854	500	0.75	0.185	0.03696	900	0.55	0.185	0.0555	0	1	0.0063	0.6482	0.9328	
	Outcome 26	0.185	0.01854	500	0.75	0.185	0.03696	900	0.55	0.63	0.0555	20	0.99	0.0216	0.6477	0.9326	
	Outcome 27	0.185	0.01854	500	0.75	0.185	0.03696	900	0.55	0.185	0.0555	50	0.975	0.0063	0.6468	0.9323	

E(U) Data for Dergis-Sherman: DoD – E(U) Calculations

R=	0.269	DoD				PM				Base				Total	Value of	Utility of	EU of
Alternative		Prob.	Weight	Score (X)	Value	P	W	X	V	P	W	X	V	Prob.	Outcome	Outcome	Alt
Dergis-	Outcome 1	0.185	0.01854	600	0.7	0.185	0.03696	800	0.6	0.185	0.0555	200	0.9	0.0063	0.4124	0.8036	
Sherman	Outcome 2	0.185	0.01854	600	0.7	0.185	0.03696	800	0.6	0.63	0.0555	400	0.8	0.0216	0.4068	0.7990	
	Outcome 3	0.185	0.01854	600	0.7	0.185	0.03696	800	0.6	0.185	0.0555	600	0.7	0.0063	0.4013	0.7943	
	Outcome 4	0.185	0.01854	600	0.7	0.63	0.03696	1000	0.5	0.185	0.0555	200	0.9	0.0216	0.4087	0.8006	
	Outcome 5	0.185	0.01854	600	0.7	0.63	0.03696	1000	0.5	0.63	0.0555	400	0.8	0.0734	0.4031	0.7959	
	Outcome 6	0.185	0.01854	600	0.7	0.63	0.03696	1000	0.5	0.185	0.0555	600	0.7	0.0216	0.3976	0.7911	
	Outcome 7	0.185	0.01854	600	0.7	0.185	0.03696	1200	0.4	0.185	0.0555	200	0.9	0.0063	0.4050	0.7975	
	Outcome 8	0.185	0.01854	600	0.7	0.185	0.03696	1200	0.4	0.63	0.0555	400	0.8	0.0216	0.3994	0.7927	
	Outcome 9	0.185	0.01854	600	0.7	0.185	0.03696	1200	0.4	0.185	0.0555	600	0.7	0.0063	0.3939	0.7879	
	Outcome 10	0.63	0.01854	800	0.6	0.185	0.03696	800	0.6	0.185	0.0555	200	0.9	0.0216	0.4105	0.8021	
	Outcome 11	0.63	0.01854	800	0.6	0.185	0.03696	800	0.6	0.63	0.0555	400	0.8	0.0734	0.4050	0.7975	
	Outcome 12	0.63	0.01854	800	0.6	0.185	0.03696	800	0.6	0.185	0.0555	600	0.7	0.0216	0.3994	0.7927	
	Outcome 13	0.63	0.01854	800	0.6	0.63	0.03696	1000	0.5	0.185	0.0555	200	0.9	0.0734	0.4068	0.7990	
	Outcome 14	0.63	0.01854	800	0.6	0.63	0.03696	1000	0.5	0.63	0.0555	400	0.8	0.2500	0.4013	0.7943	0.7943
	Outcome 15	0.63	0.01854	800	0.6	0.63	0.03696	1000	0.5	0.185	0.0555	600	0.7	0.0734	0.3957	0.7895	
	Outcome 16	0.63	0.01854	800	0.6	0.185	0.03696	1200	0.4	0.185	0.0555	200	0.9	0.0216	0.4031	0.7959	
	Outcome 17	0.63	0.01854	800	0.6	0.185	0.03696	1200	0.4	0.63	0.0555	400	0.8	0.0734	0.3976	0.7911	
	Outcome 18	0.63	0.01854	800	0.6	0.185	0.03696	1200	0.4	0.185	0.0555	600	0.7	0.0216	0.3920	0.7863	
	Outcome 19	0.185	0.01854	1000	0.5	0.185	0.03696	800	0.6	0.185	0.0555	200	0.9	0.0063	0.4087	0.8006	
	Outcome 20	0.185	0.01854	1000	0.5	0.185	0.03696	800	0.6	0.63	0.0555	400	0.8	0.0216	0.4031	0.7959	
	Outcome 21	0.185	0.01854	1000	0.5	0.185	0.03696	800	0.6	0.185	0.0555	600	0.7	0.0063	0.3976	0.7911	
	Outcome 22	0.185	0.01854	1000	0.5	0.63	0.03696	1000	0.5	0.185	0.0555	200	0.9	0.0216	0.4050	0.7975	
	Outcome 23	0.185	0.01854	1000	0.5	0.63	0.03696	1000	0.5	0.63	0.0555	400	0.8	0.0734	0.3994	0.7927	
	Outcome 24	0.185	0.01854	1000	0.5	0.63	0.03696	1000	0.5	0.185	0.0555	600	0.7	0.0216	0.3939	0.7879	
	Outcome 25	0.185	0.01854	1000	0.5	0.185	0.03696	1200	0.4	0.185	0.0555	200	0.9	0.0063	0.4013	0.7943	
	Outcome 26	0.185	0.01854	1000	0.5	0.185	0.03696	1200	0.4	0.63	0.0555	400	0.8	0.0216	0.3957	0.7895	
	Outcome 27	0.185	0.01854	1000	0.5	0.185	0.03696	1200	0.4	0.185	0.0555	600	0.7	0.0063	0.3902	0.7846	

E(U) Data for Facilities Renewal: DoD – E(U) Calculations

R=	0.269	DoD				PM				Base				Total	Value of	Utility of	EU of
Alternative		**Prob.**	**Weight**	**Score (X)**	**Value**	**P**	**W**	**X**	**V**	**P**	**W**	**X**	**V**	**Prob.**	**Outcome**	**Outcome**	**Alt**
Facilities	Outcome 1	0.185	0.01854	600	0.7	0.185	0.03696	800	0.6	0.185	0.0555	200	0.9	0.0063	0.4201	0.8099	
Renewal	Outcome 2	0.185	0.01854	600	0.7	0.185	0.03696	800	0.6	0.63	0.0555	400	0.8	0.0216	0.4146	0.8054	
	Outcome 3	0.185	0.01854	600	0.7	0.185	0.03696	800	0.6	0.185	0.0555	600	0.7	0.0063	0.4090	0.8009	
	Outcome 4	0.185	0.01854	600	0.7	0.63	0.03696	1250	0.375	0.185	0.0555	200	0.9	0.0216	0.4118	0.8032	
	Outcome 5	0.185	0.01854	600	0.7	0.63	0.03696	1250	0.375	0.63	0.0555	400	0.8	0.0734	0.4063	0.7986	
	Outcome 6	0.185	0.01854	600	0.7	0.63	0.03696	1250	0.375	0.185	0.0555	600	0.7	0.0216	0.4007	0.7938	
	Outcome 7	0.185	0.01854	600	0.7	0.185	0.03696	1500	0.25	0.185	0.0555	200	0.9	0.0063	0.4072	0.7993	
	Outcome 8	0.185	0.01854	600	0.7	0.185	0.03696	1500	0.25	0.63	0.0555	400	0.8	0.0216	0.4017	0.7946	
	Outcome 9	0.185	0.01854	600	0.7	0.185	0.03696	1500	0.25	0.185	0.0555	600	0.7	0.0063	0.3961	0.7898	
	Outcome 10	0.63	0.01854	800	0.6	0.185	0.03696	800	0.6	0.185	0.0555	200	0.9	0.0216	0.4183	0.8084	
	Outcome 11	0.63	0.01854	800	0.6	0.185	0.03696	800	0.6	0.63	0.0555	400	0.8	0.0734	0.4127	0.8039	
	Outcome 12	0.63	0.01854	800	0.6	0.185	0.03696	800	0.6	0.185	0.0555	600	0.7	0.0216	0.4072	0.7993	
	Outcome 13	0.63	0.01854	800	0.6	0.63	0.03696	1250	0.375	0.185	0.0555	200	0.9	0.0734	0.4100	0.8016	
	Outcome 14	0.63	0.01854	800	0.6	0.63	0.03696	1250	0.375	0.63	0.0555	400	0.8	0.2500	0.4044	0.7970	0.7975
	Outcome 15	0.63	0.01854	800	0.6	0.63	0.03696	1250	0.375	0.185	0.0555	600	0.7	0.0734	0.3989	0.7922	
	Outcome 16	0.63	0.01854	800	0.6	0.185	0.03696	1500	0.25	0.185	0.0555	200	0.9	0.0216	0.4053	0.7978	
	Outcome 17	0.63	0.01854	800	0.6	0.185	0.03696	1500	0.25	0.63	0.0555	400	0.8	0.0734	0.3998	0.7930	
	Outcome 18	0.63	0.01854	800	0.6	0.185	0.03696	1500	0.25	0.185	0.0555	600	0.7	0.0216	0.3942	0.7882	
	Outcome 19	0.185	0.01854	1000	0.5	0.185	0.03696	800	0.6	0.185	0.0555	200	0.9	0.0063	0.4164	0.8069	
	Outcome 20	0.185	0.01854	1000	0.5	0.185	0.03696	800	0.6	0.63	0.0555	400	0.8	0.0216	0.4109	0.8024	
	Outcome 21	0.185	0.01854	1000	0.5	0.185	0.03696	800	0.6	0.185	0.0555	600	0.7	0.0063	0.4053	0.7978	
	Outcome 22	0.185	0.01854	1000	0.5	0.63	0.03696	1250	0.375	0.185	0.0555	200	0.9	0.0216	0.4081	0.8001	
	Outcome 23	0.185	0.01854	1000	0.5	0.63	0.03696	1250	0.375	0.63	0.0555	400	0.8	0.0734	0.4026	0.7954	
	Outcome 24	0.185	0.01854	1000	0.5	0.63	0.03696	1250	0.375	0.185	0.0555	600	0.7	0.0216	0.3970	0.7906	
	Outcome 25	0.185	0.01854	1000	0.5	0.185	0.03696	1500	0.25	0.185	0.0555	200	0.9	0.0063	0.4035	0.7962	
	Outcome 26	0.185	0.01854	1000	0.5	0.185	0.03696	1500	0.25	0.63	0.0555	400	0.8	0.0216	0.3979	0.7914	
	Outcome 27	0.185	0.01854	1000	0.5	0.185	0.03696	1500	0.25	0.185	0.0555	600	0.7	0.0063	0.3924	0.7866	

E(U) Data for Depreciation: DoD – E(U) Calculations

R=	0.269	**DoD**				**PM**				**Base**				Total	Value of	Utility of	EU of
	Alternative	**Prob.**	**Weight**	**Score (X)**	**Value**	**P**	**W**	**X**	**V**	**P**	**W**	**X**	**V**	Prob	Outcome	Outcome	Alt
Dep.	Outcome 1	0.185	0.01854	800	0.6	0.185	0.03696	800	0.6	0.185	0.0555	0	1	0.0063	0.6751	0.9416	
	Outcome 2	0.185	0.01854	800	0.6	0.185	0.03696	800	0.6	0.63	0.0555	20	0.99	0.0216	0.6745	0.9414	
	Outcome 3	0.185	0.01854	800	0.6	0.185	0.03696	800	0.6	0.185	0.0555	100	0.95	0.0063	0.6723	0.9407	
	Outcome 4	0.185	0.01854	800	0.6	0.63	0.03696	1200	0.4	0.185	0.0555	0	1	0.0216	0.6677	0.9393	
	Outcome 5	0.185	0.01854	800	0.6	0.63	0.03696	1200	0.4	0.63	0.0555	20	0.99	0.0734	0.6672	0.9391	
	Outcome 6	0.185	0.01854	800	0.6	0.63	0.03696	1200	0.4	0.185	0.0555	100	0.95	0.0216	0.6649	0.9384	
	Outcome 7	0.185	0.01854	800	0.6	0.185	0.03696	1500	0.25	0.185	0.0555	0	1	0.0063	0.6622	0.9375	
	Outcome 8	0.185	0.01854	800	0.6	0.185	0.03696	1500	0.25	0.63	0.0555	20	0.99	0.0216	0.6616	0.9373	
	Outcome 9	0.185	0.01854	800	0.6	0.185	0.03696	1500	0.25	0.185	0.0555	100	0.95	0.0063	0.6594	0.9366	
	Outcome 10	0.63	0.01854	1000	0.5	0.185	0.03696	800	0.6	0.185	0.0555	0	1	0.0216	0.6732	0.9410	
	Outcome 11	0.63	0.01854	1000	0.5	0.185	0.03696	800	0.6	0.63	0.0555	20	0.99	0.0734	0.6727	0.9408	
	Outcome 12	0.63	0.01854	1000	0.5	0.185	0.03696	800	0.6	0.185	0.0555	100	0.95	0.0216	0.6705	0.9401	
	Outcome 13	0.63	0.01854	1000	0.5	0.63	0.03696	1200	0.4	0.185	0.0555	0	1	0.0734	0.6659	0.9387	
	Outcome 14	0.63	0.01854	1000	0.5	0.63	0.03696	1200	0.4	0.63	0.0555	20	0.99	0.2500	0.6653	0.9385	0.9383
	Outcome 15	0.63	0.01854	1000	0.5	0.63	0.03696	1200	0.4	0.185	0.0555	100	0.95	0.0734	0.6631	0.9378	
	Outcome 16	0.63	0.01854	1000	0.5	0.185	0.03696	1500	0.25	0.185	0.0555	0	1	0.0216	0.6603	0.9369	
	Outcome 17	0.63	0.01854	1000	0.5	0.185	0.03696	1500	0.25	0.63	0.0555	20	0.99	0.0734	0.6598	0.9367	
	Outcome 18	0.63	0.01854	1000	0.5	0.185	0.03696	1500	0.25	0.185	0.0555	100	0.95	0.0216	0.6575	0.9360	
	Outcome 19	0.185	0.01854	1500	0.25	0.185	0.03696	800	0.6	0.185	0.0555	0	1	0.0063	0.6686	0.9395	
	Outcome 20	0.185	0.01854	1500	0.25	0.185	0.03696	800	0.6	0.63	0.0555	20	0.99	0.0216	0.6681	0.9394	
	Outcome 21	0.185	0.01854	1500	0.25	0.185	0.03696	800	0.6	0.185	0.0555	100	0.95	0.0063	0.6658	0.9387	
	Outcome 22	0.185	0.01854	1500	0.25	0.63	0.03696	1200	0.4	0.185	0.0555	0	1	0.0216	0.6612	0.9372	
	Outcome 23	0.185	0.01854	1500	0.25	0.63	0.03696	1200	0.4	0.63	0.0555	20	0.99	0.0734	0.6607	0.9370	
	Outcome 24	0.185	0.01854	1500	0.25	0.63	0.03696	1200	0.4	0.185	0.0555	100	0.95	0.0216	0.6584	0.9363	
	Outcome 25	0.185	0.01854	1500	0.25	0.185	0.03696	1500	0.25	0.185	0.0555	0	1	0.0063	0.6557	0.9353	
	Outcome 26	0.185	0.01854	1500	0.25	0.185	0.03696	1500	0.25	0.63	0.0555	20	0.99	0.0216	0.6551	0.9352	
	Outcome 27	0.185	0.01854	1500	0.25	0.185	0.03696	1500	0.25	0.185	0.0555	100	0.95	0.0063	0.6529	0.9344	

E(U) Data for BUILDER: DoD – E(U) Calculations

R=	0.269	DoD				PM				Base				Total	Value of	Utility of	EU of
	Alternative: BUILDER	Prob.	Weight	Score (X)	Value	P	W	X	V	P	W	X	V	Prob	Outcome	Outcome	Alt
	Outcome 1	0.185	0.01854	500	0.75	0.185	0.03696	500	0.75	0.185	0.0555	1500	0.25	0.0063	0.5538	0.8941	
	Outcome 2	0.185	0.01854	500	0.75	0.185	0.03696	500	0.75	0.63	0.0555	1700	0.15	0.0216	0.5482	0.8914	
	Outcome 3	0.185	0.01854	500	0.75	0.185	0.03696	500	0.75	0.185	0.0555	2000	0	0.0063	0.5399	0.8872	
	Outcome 4	0.185	0.01854	500	0.75	0.63	0.03696	1000	0.5	0.185	0.0555	1500	0.25	0.0216	0.5445	0.8895	
	Outcome 5	0.185	0.01854	500	0.75	0.63	0.03696	1000	0.5	0.63	0.0555	1700	0.15	0.0734	0.5390	0.8867	
	Outcome 6	0.185	0.01854	500	0.75	0.63	0.03696	1000	0.5	0.185	0.0555	2000	0	0.0216	0.5306	0.8823	
	Outcome 7	0.185	0.01854	500	0.75	0.185	0.03696	1500	0.25	0.185	0.0555	1500	0.25	0.0063	0.5353	0.8848	
	Outcome 8	0.185	0.01854	500	0.75	0.185	0.03696	1500	0.25	0.63	0.0555	1700	0.15	0.0216	0.5297	0.8819	
	Outcome 9	0.185	0.01854	500	0.75	0.185	0.03696	1500	0.25	0.185	0.0555	2000	0	0.0063	0.5214	0.8774	
	Outcome 10	0.63	0.01854	1000	0.5	0.185	0.03696	500	0.75	0.185	0.0555	1500	0.25	0.0216	0.5491	0.8918	
	Outcome 11	0.63	0.01854	1000	0.5	0.185	0.03696	500	0.75	0.63	0.0555	1700	0.15	0.0734	0.5436	0.8890	
	Outcome 12	0.63	0.01854	1000	0.5	0.185	0.03696	500	0.75	0.185	0.0555	2000	0	0.0216	0.5352	0.8848	
	Outcome 13	0.63	0.01854	1000	0.5	0.63	0.03696	1000	0.5	0.185	0.0555	1500	0.25	0.0734	0.5399	0.8872	
	Outcome 14	0.63	0.01854	1000	0.5	0.63	0.03696	1000	0.5	0.63	0.0555	1700	0.15	0.2500	0.5343	0.8843	0.8840
	Outcome 15	0.63	0.01854	1000	0.5	0.63	0.03696	1000	0.5	0.185	0.0555	2000	0	0.0734	0.5260	0.8799	
	Outcome 16	0.63	0.01854	1000	0.5	0.185	0.03696	1500	0.25	0.185	0.0555	1500	0.25	0.0216	0.5306	0.8823	
	Outcome 17	0.63	0.01854	1000	0.5	0.185	0.03696	1500	0.25	0.63	0.0555	1700	0.15	0.0734	0.5251	0.8794	
	Outcome 18	0.63	0.01854	1000	0.5	0.185	0.03696	1500	0.25	0.185	0.0555	2000	0	0.0216	0.5168	0.8748	
	Outcome 19	0.185	0.01854	1500	0.25	0.185	0.03696	500	0.75	0.185	0.0555	1500	0.25	0.0063	0.5445	0.8895	
	Outcome 20	0.185	0.01854	1500	0.25	0.185	0.03696	500	0.75	0.63	0.0555	1700	0.15	0.0216	0.5389	0.8867	
	Outcome 21	0.185	0.01854	1500	0.25	0.185	0.03696	500	0.75	0.185	0.0555	2000	0	0.0063	0.5306	0.8823	
	Outcome 22	0.185	0.01854	1500	0.25	0.63	0.03696	1000	0.5	0.185	0.0555	1500	0.25	0.0216	0.5352	0.8848	
	Outcome 23	0.185	0.01854	1500	0.25	0.63	0.03696	1000	0.5	0.63	0.0555	1700	0.15	0.0734	0.5297	0.8818	
	Outcome 24	0.185	0.01854	1500	0.25	0.63	0.03696	1000	0.5	0.185	0.0555	2000	0	0.0216	0.5214	0.8774	
	Outcome 25	0.185	0.01854	1500	0.25	0.185	0.03696	1500	0.25	0.185	0.0555	1500	0.25	0.0063	0.5260	0.8799	
	Outcome 26	0.185	0.01854	1500	0.25	0.185	0.03696	1500	0.25	0.63	0.0555	1700	0.15	0.0216	0.5205	0.8768	
	Outcome 27	0.185	0.01854	1500	0.25	0.185	0.03696	1500	0.25	0.185	0.0555	2000	0	0.0063	0.5121	0.8722	

E(U) Data for Renewal Factors: DoD – E(U) Calculations

R=	0.269	DoD				PM				Base				Total Prob	Value of Outcome	Utility of Outcome	EU of Alt
Alternative		**Prob.**	**Weight**	**Score (X)**	**Value**	**P**	**W**	**X**	**V**	**P**	**W**	**X**	**V**				
Renewal	Outcome 1	0.185	0.0185	500	0.75	0.185	0.0370	500	0.75	0.185	0.0555	1500	0.25	0.0063	0.5538	0.8941	
Factors	Outcome 2	0.185	0.0185	500	0.75	0.185	0.0370	500	0.75	0.63	0.0555	1700	0.15	0.0216	0.5482	0.8914	
	Outcome 3	0.185	0.0185	500	0.75	0.185	0.0370	500	0.75	0.185	0.0555	2000	0	0.0063	0.5399	0.8872	
	Outcome 4	0.185	0.0185	500	0.75	0.63	0.0370	1000	0.5	0.185	0.0555	1500	0.25	0.0216	0.5445	0.8895	
	Outcome 5	0.185	0.0185	500	0.75	0.63	0.0370	1000	0.5	0.63	0.0555	1700	0.15	0.0734	0.5390	0.8867	
	Outcome 6	0.185	0.0185	500	0.75	0.63	0.0370	1000	0.5	0.185	0.0555	2000	0	0.0216	0.5306	0.8823	
	Outcome 7	0.185	0.0185	500	0.75	0.185	0.0370	1500	0.25	0.185	0.0555	1500	0.25	0.0063	0.5353	0.8848	
	Outcome 8	0.185	0.0185	500	0.75	0.185	0.0370	1500	0.25	0.63	0.0555	1700	0.15	0.0216	0.5297	0.8819	
	Outcome 9	0.185	0.0185	500	0.75	0.185	0.0370	1500	0.25	0.185	0.0555	2000	0	0.0063	0.5214	0.8774	
	Outcome 10	0.63	0.0185	1000	0.5	0.185	0.0370	500	0.75	0.185	0.0555	1500	0.25	0.0216	0.5491	0.8918	
	Outcome 11	0.63	0.0185	1000	0.5	0.185	0.0370	500	0.75	0.63	0.0555	1700	0.15	0.0734	0.5436	0.8890	
	Outcome 12	0.63	0.0185	1000	0.5	0.185	0.0370	500	0.75	0.185	0.0555	2000	0	0.0216	0.5352	0.8848	
	Outcome 13	0.63	0.0185	1000	0.5	0.63	0.0370	1000	0.5	0.185	0.0555	1500	0.25	0.0734	0.5399	0.8872	
	Outcome 14	0.63	0.0185	1000	0.5	0.63	0.0370	1000	0.5	0.63	0.0555	1700	0.15	0.2500	0.5343	0.8843	0.8840
	Outcome 15	0.63	0.0185	1000	0.5	0.63	0.0370	1000	0.5	0.185	0.0555	2000	0	0.0734	0.5260	0.8799	
	Outcome 16	0.63	0.0185	1000	0.5	0.185	0.0370	1500	0.25	0.185	0.0555	1500	0.25	0.0216	0.5306	0.8823	
	Outcome 17	0.63	0.0185	1000	0.5	0.185	0.0370	1500	0.25	0.63	0.0555	1700	0.15	0.0734	0.5251	0.8794	
	Outcome 18	0.63	0.0185	1000	0.5	0.185	0.0370	1500	0.25	0.185	0.0555	2000	0	0.0216	0.5168	0.8748	
	Outcome 19	0.185	0.0185	1500	0.25	0.185	0.0370	500	0.75	0.185	0.0555	1500	0.25	0.0063	0.5445	0.8895	
	Outcome 20	0.185	0.0185	1500	0.25	0.185	0.0370	500	0.75	0.63	0.0555	1700	0.15	0.0216	0.5389	0.8867	
	Outcome 21	0.185	0.0185	1500	0.25	0.185	0.0370	500	0.75	0.185	0.0555	2000	0	0.0063	0.5306	0.8823	
	Outcome 22	0.185	0.0185	1500	0.25	0.63	0.0370	1000	0.5	0.185	0.0555	1500	0.25	0.0216	0.5352	0.8848	
	Outcome 23	0.185	0.0185	1500	0.25	0.63	0.0370	1000	0.5	0.63	0.0555	1700	0.15	0.0734	0.5297	0.8818	
	Outcome 24	0.185	0.0185	1500	0.25	0.63	0.0370	1000	0.5	0.185	0.0555	2000	0	0.0216	0.5214	0.8774	
	Outcome 25	0.185	0.0185	1500	0.25	0.185	0.0370	1500	0.25	0.185	0.0555	1500	0.25	0.0063	0.5260	0.8799	
	Outcome 26	0.185	0.0185	1500	0.25	0.185	0.0370	1500	0.25	0.63	0.0555	1700	0.15	0.0216	0.5205	0.8768	
	Outcome 27	0.185	0.0185	1500	0.25	0.185	0.0370	1500	0.25	0.185	0.0555	2000	0	0.0063	0.5121	0.8722	

E(U) Data for AME: DoD – E(U) Calculations

R=	0.269	DoD				PM				Base				Total	Value of	Utility of	EU of
Alternative		Prob.	Weight	Score (X)	Value	P	W	X	V	P	W	X	V	Prob	Outcome	Outcome	Alt
AME	Outcome 1	0.185	0.0185	300	0.85	0.185	0.0370	300	0.85	0.185	0.0555	1000	0.5	0.0063	0.6088	0.9183	
	Outcome 2	0.185	0.0185	300	0.85	0.185	0.0370	300	0.85	0.63	0.0555	1500	0.25	0.0216	0.5950	0.9127	
	Outcome 3	0.185	0.0185	300	0.85	0.185	0.0370	300	0.85	0.185	0.0555	2000	0	0.0063	0.5811	0.9067	
	Outcome 4	0.185	0.0185	300	0.85	0.63	0.0370	500	0.75	0.185	0.0555	1000	0.5	0.0216	0.6051	0.9168	
	Outcome 5	0.185	0.0185	300	0.85	0.63	0.0370	500	0.75	0.63	0.0555	1500	0.25	0.0734	0.5913	0.9111	
	Outcome 6	0.185	0.0185	300	0.85	0.63	0.0370	500	0.75	0.185	0.0555	2000	0	0.0216	0.5774	0.9051	
	Outcome 7	0.185	0.0185	300	0.85	0.185	0.0370	800	0.6	0.185	0.0555	1000	0.5	0.0063	0.5996	0.9146	
	Outcome 8	0.185	0.0185	300	0.85	0.185	0.0370	800	0.6	0.63	0.0555	1500	0.25	0.0216	0.5857	0.9087	
	Outcome 9	0.185	0.0185	300	0.85	0.185	0.0370	800	0.6	0.185	0.0555	2000	0	0.0063	0.5719	0.9026	
	Outcome 10	0.63	0.0185	500	0.75	0.185	0.0370	300	0.85	0.185	0.0555	1000	0.5	0.0216	0.6070	0.9176	
	Outcome 11	0.63	0.0185	500	0.75	0.185	0.0370	300	0.85	0.63	0.0555	1500	0.25	0.0734	0.5931	0.9119	
	Outcome 12	0.63	0.0185	500	0.75	0.185	0.0370	300	0.85	0.185	0.0555	2000	0	0.0216	0.5792	0.9059	
	Outcome 13	0.63	0.0185	500	0.75	0.63	0.0370	500	0.75	0.185	0.0555	1000	0.5	0.0734	0.6033	0.9161	
	Outcome 14	0.63	0.0185	500	0.75	0.63	0.0370	500	0.75	0.63	0.0555	1500	0.25	0.2500	0.5894	0.9103	0.9100
	Outcome 15	0.63	0.0185	500	0.75	0.63	0.0370	500	0.75	0.185	0.0555	2000	0	0.0734	0.5755	0.9043	
	Outcome 16	0.63	0.0185	500	0.75	0.185	0.0370	800	0.6	0.185	0.0555	1000	0.5	0.0216	0.5977	0.9138	
	Outcome 17	0.63	0.0185	500	0.75	0.185	0.0370	800	0.6	0.63	0.0555	1500	0.25	0.0734	0.5839	0.9079	
	Outcome 18	0.63	0.0185	500	0.75	0.185	0.0370	800	0.6	0.185	0.0555	2000	0	0.0216	0.5700	0.9018	
	Outcome 19	0.185	0.0185	800	0.6	0.185	0.0370	300	0.85	0.185	0.0555	1000	0.5	0.0063	0.6042	0.9165	
	Outcome 20	0.185	0.0185	800	0.6	0.185	0.0370	300	0.85	0.63	0.0555	1500	0.25	0.0216	0.5903	0.9107	
	Outcome 21	0.185	0.0185	800	0.6	0.185	0.0370	300	0.85	0.185	0.0555	2000	0	0.0063	0.5765	0.9047	
	Outcome 22	0.185	0.0185	800	0.6	0.63	0.0370	500	0.75	0.185	0.0555	1000	0.5	0.0216	0.6005	0.9150	
	Outcome 23	0.185	0.0185	800	0.6	0.63	0.0370	500	0.75	0.63	0.0555	1500	0.25	0.0734	0.5866	0.9091	
	Outcome 24	0.185	0.0185	800	0.6	0.63	0.0370	500	0.75	0.185	0.0555	2000	0	0.0216	0.5728	0.9030	
	Outcome 25	0.185	0.0185	800	0.6	0.185	0.0370	800	0.6	0.185	0.0555	1000	0.5	0.0063	0.5950	0.9127	
	Outcome 26	0.185	0.0185	800	0.6	0.185	0.0370	800	0.6	0.63	0.0555	1500	0.25	0.0216	0.5811	0.9067	
	Outcome 27	0.185	0.0185	800	0.6	0.185	0.0370	800	0.6	0.185	0.0555	2000	0	0.0063	0.5672	0.9005	

E(U) Data for FRM: DoD – E(U) Calculations

R=	0.269	DoD				PM				Base				Total	Value of	Utility of	EU of
	Alternative	**Prob.**	**Weight**	**Score (X)**	**V**	**P**	**W**	**X**	**V**	**P**	**W**	**X**	**V**	Prob.	Outcome	Outcome	Alt
FRM	Outcome 1	0.185	0.01854	50	0.975	0.185	0.03696	100	0.95	0.185	0.0555	5	0.9975	0.0063	0.5991	0.9144	
	Outcome 2	0.185	0.01854	50	0.975	0.185	0.03696	100	0.95	0.63	0.0555	20	0.99	0.0216	0.5987	0.9142	
	Outcome 3	0.185	0.01854	50	0.975	0.185	0.03696	100	0.95	0.185	0.0555	30	0.985	0.0063	0.5984	0.9141	
	Outcome 4	0.185	0.01854	50	0.975	0.63	0.03696	200	0.9	0.185	0.0555	5	0.9975	0.0216	0.5973	0.9136	
	Outcome 5	0.185	0.01854	50	0.975	0.63	0.03696	200	0.9	0.63	0.0555	20	0.99	0.0734	0.5969	0.9135	
	Outcome 6	0.185	0.01854	50	0.975	0.63	0.03696	200	0.9	0.185	0.0555	30	0.985	0.0216	0.5966	0.9133	
	Outcome 7	0.185	0.01854	50	0.975	0.185	0.03696	300	0.85	0.185	0.0555	5	0.9975	0.0063	0.5954	0.9129	
	Outcome 8	0.185	0.01854	50	0.975	0.185	0.03696	300	0.85	0.63	0.0555	20	0.99	0.0216	0.5950	0.9127	
	Outcome 9	0.185	0.01854	50	0.975	0.185	0.03696	300	0.85	0.185	0.0555	30	0.985	0.0063	0.5947	0.9126	
	Outcome 10	0.63	0.01854	100	0.95	0.185	0.03696	100	0.95	0.185	0.0555	5	0.9975	0.0216	0.5987	0.9142	
	Outcome 11	0.63	0.01854	100	0.95	0.185	0.03696	100	0.95	0.63	0.0555	20	0.99	0.0734	0.5983	0.9140	
	Outcome 12	0.63	0.01854	100	0.95	0.185	0.03696	100	0.95	0.185	0.0555	30	0.985	0.0216	0.5980	0.9139	
	Outcome 13	0.63	0.01854	100	0.95	0.63	0.03696	200	0.9	0.185	0.0555	5	0.9975	0.0734	0.5968	0.9134	
	Outcome 14	0.63	0.01854	100	0.95	0.63	0.03696	200	0.9	0.63	0.0555	20	0.99	0.2500	0.5964	0.9133	0.9132
	Outcome 15	0.63	0.01854	100	0.95	0.63	0.03696	200	0.9	0.185	0.0555	30	0.985	0.0734	0.5961	0.9132	
	Outcome 16	0.63	0.01854	100	0.95	0.185	0.03696	300	0.85	0.185	0.0555	5	0.9975	0.0216	0.5950	0.9127	
	Outcome 17	0.63	0.01854	100	0.95	0.185	0.03696	300	0.85	0.63	0.0555	20	0.99	0.0734	0.5946	0.9125	
	Outcome 18	0.63	0.01854	100	0.95	0.185	0.03696	300	0.85	0.185	0.0555	30	0.985	0.0216	0.5943	0.9124	
	Outcome 19	0.185	0.01854	200	0.9	0.185	0.03696	100	0.95	0.185	0.0555	5	0.9975	0.0063	0.5977	0.9138	
	Outcome 20	0.185	0.01854	200	0.9	0.185	0.03696	100	0.95	0.63	0.0555	20	0.99	0.0216	0.5973	0.9136	
	Outcome 21	0.185	0.01854	200	0.9	0.185	0.03696	100	0.95	0.185	0.0555	30	0.985	0.0063	0.5971	0.9135	
	Outcome 22	0.185	0.01854	200	0.9	0.63	0.03696	200	0.9	0.185	0.0555	5	0.9975	0.0216	0.5959	0.9131	
	Outcome 23	0.185	0.01854	200	0.9	0.63	0.03696	200	0.9	0.63	0.0555	20	0.99	0.0734	0.5955	0.9129	
	Outcome 24	0.185	0.01854	200	0.9	0.63	0.03696	200	0.9	0.185	0.0555	30	0.985	0.0216	0.5952	0.9128	
	Outcome 25	0.185	0.01854	200	0.9	0.185	0.03696	300	0.85	0.185	0.0555	5	0.9975	0.0063	0.5941	0.9123	
	Outcome 26	0.185	0.01854	200	0.9	0.185	0.03696	300	0.85	0.63	0.0555	20	0.99	0.0216	0.5936	0.9121	
	Outcome 27	0.185	0.01854	200	0.9	0.185	0.03696	300	0.85	0.185	0.0555	30	0.985	0.0063	0.5934	0.9120	

E(U) Data for FMM: DoD – E(U) Calculations

R=	0.269	DoD				PM				Base				Total Prob	Value of Outcome	Utility of Outcome	EU of Alt
Alternative		P	W	X	V	P	W	X	V	P	W	X	V				
FMM	Outcome 1	0.185	0.0185	50	0.975	0.185	0.0370	200	0.9	0.185	0.0555	10	0.995	0.0063	0.6929	0.9469	
	Outcome 2	0.185	0.0185	50	0.975	0.185	0.0370	200	0.9	0.63	0.0555	50	0.975	0.0216	0.6917	0.9466	
	Outcome 3	0.185	0.0185	50	0.975	0.185	0.0370	200	0.9	0.185	0.0555	90	0.955	0.0063	0.6906	0.9463	
	Outcome 4	0.185	0.0185	50	0.975	0.63	0.0370	250	0.875	0.185	0.0555	10	0.995	0.0216	0.6919	0.9466	
	Outcome 5	0.185	0.0185	50	0.975	0.63	0.0370	250	0.875	0.63	0.0555	50	0.975	0.0734	0.6908	0.9463	
	Outcome 6	0.185	0.0185	50	0.975	0.63	0.0370	250	0.875	0.185	0.0555	90	0.955	0.0216	0.6897	0.9460	
	Outcome 7	0.185	0.0185	50	0.975	0.185	0.0370	300	0.85	0.185	0.0555	10	0.995	0.0063	0.6910	0.9464	
	Outcome 8	0.185	0.0185	50	0.975	0.185	0.0370	300	0.85	0.63	0.0555	50	0.975	0.0216	0.6899	0.9460	
	Outcome 9	0.185	0.0185	50	0.975	0.185	0.0370	300	0.85	0.185	0.0555	90	0.955	0.0063	0.6888	0.9457	
	Outcome 10	0.63	0.0185	150	0.925	0.185	0.0370	200	0.9	0.185	0.0555	10	0.995	0.0216	0.6919	0.9466	
	Outcome 11	0.63	0.0185	150	0.925	0.185	0.0370	200	0.9	0.63	0.0555	50	0.975	0.0734	0.6908	0.9463	
	Outcome 12	0.63	0.0185	150	0.925	0.185	0.0370	200	0.9	0.185	0.0555	90	0.955	0.0216	0.6897	0.9460	
	Outcome 13	0.63	0.0185	150	0.925	0.63	0.0370	250	0.875	0.185	0.0555	10	0.995	0.0734	0.6910	0.9464	
	Outcome 14	0.63	0.0185	150	0.925	0.63	0.0370	250	0.875	0.63	0.0555	50	0.975	0.2500	0.6899	0.9460	0.9461
	Outcome 15	0.63	0.0185	150	0.925	0.63	0.0370	250	0.875	0.185	0.0555	90	0.955	0.0734	0.6888	0.9457	
	Outcome 16	0.63	0.0185	150	0.925	0.185	0.0370	300	0.85	0.185	0.0555	10	0.995	0.0216	0.6901	0.9461	
	Outcome 17	0.63	0.0185	150	0.925	0.185	0.0370	300	0.85	0.63	0.0555	50	0.975	0.0734	0.6890	0.9458	
	Outcome 18	0.63	0.0185	150	0.925	0.185	0.0370	300	0.85	0.185	0.0555	90	0.955	0.0216	0.6879	0.9454	
	Outcome 19	0.185	0.0185	200	0.9	0.185	0.0370	200	0.9	0.185	0.0555	10	0.995	0.0063	0.6915	0.9465	
	Outcome 20	0.185	0.0185	200	0.9	0.185	0.0370	200	0.9	0.63	0.0555	50	0.975	0.0216	0.6904	0.9462	
	Outcome 21	0.185	0.0185	200	0.9	0.185	0.0370	200	0.9	0.185	0.0555	90	0.955	0.0063	0.6892	0.9458	
	Outcome 22	0.185	0.0185	200	0.9	0.63	0.0370	250	0.875	0.185	0.0555	10	0.995	0.0216	0.6905	0.9462	
	Outcome 23	0.185	0.0185	200	0.9	0.63	0.0370	250	0.875	0.63	0.0555	50	0.975	0.0734	0.6894	0.9459	
	Outcome 24	0.185	0.0185	200	0.9	0.63	0.0370	250	0.875	0.185	0.0555	90	0.955	0.0216	0.6883	0.9456	
	Outcome 25	0.185	0.0185	200	0.9	0.185	0.0370	300	0.85	0.185	0.0555	10	0.995	0.0063	0.6896	0.9460	
	Outcome 26	0.185	0.0185	200	0.9	0.185	0.0370	300	0.85	0.63	0.0555	50	0.975	0.0216	0.6885	0.9456	
	Outcome 27	0.185	0.0185	200	0.9	0.185	0.0370	300	0.85	0.185	0.0555	90	0.955	0.0063	0.6874	0.9453	

E(U) Data for Bottom Up: DoD – E(U) Calculations

R=	0.269	**DoD**				**PM**				**Base**				Total	Value of	Utility of	EU of
	Alternative	**Prob.**	**Weight**	**Score (X)**	**V**	**P**	**W**	**X**	**V**	**P**	**W**	**X**	**V**	Prob.	Outcome	Outcome	Alt
Bottom	Outcome 1	0.185	0.01854	10	0.995	0.185	0.03696	20	0.99	0.185	0.0555	50	0.975	0.0063	0.5187	0.8759	
Up	Outcome 2	0.185	0.01854	10	0.995	0.185	0.03696	20	0.99	0.63	0.0555	500	0.75	0.0216	0.5062	0.8688	
	Outcome 3	0.185	0.01854	10	0.995	0.185	0.03696	20	0.99	0.185	0.0555	700	0.65	0.0063	0.5007	0.8655	
	Outcome 4	0.185	0.01854	10	0.995	0.63	0.03696	50	0.975	0.185	0.0555	50	0.975	0.0216	0.5182	0.8756	
	Outcome 5	0.185	0.01854	10	0.995	0.63	0.03696	50	0.975	0.63	0.0555	500	0.75	0.0734	0.5057	0.8685	
	Outcome 6	0.185	0.01854	10	0.995	0.63	0.03696	50	0.975	0.185	0.0555	700	0.65	0.0216	0.5001	0.8652	
	Outcome 7	0.185	0.01854	10	0.995	0.185	0.03696	100	0.95	0.185	0.0555	50	0.975	0.0063	0.5172	0.8751	
	Outcome 8	0.185	0.01854	10	0.995	0.185	0.03696	100	0.95	0.63	0.0555	500	0.75	0.0216	0.5047	0.8679	
	Outcome 9	0.185	0.01854	10	0.995	0.185	0.03696	100	0.95	0.185	0.0555	700	0.65	0.0063	0.4992	0.8647	
	Outcome 10	0.63	0.01854	20	0.99	0.185	0.03696	20	0.99	0.185	0.0555	50	0.975	0.0216	0.5186	0.8758	
	Outcome 11	0.63	0.01854	20	0.99	0.185	0.03696	20	0.99	0.63	0.0555	500	0.75	0.0734	0.5061	0.8687	
	Outcome 12	0.63	0.01854	20	0.99	0.185	0.03696	20	0.99	0.185	0.0555	700	0.65	0.0216	0.5006	0.8655	
	Outcome 13	0.63	0.01854	20	0.99	0.63	0.03696	50	0.975	0.185	0.0555	50	0.975	0.0734	0.5181	0.8755	
	Outcome 14	0.63	0.01854	20	0.99	0.63	0.03696	50	0.975	0.63	0.0555	500	0.75	0.2500	0.5056	0.8684	0.8691
	Outcome 15	0.63	0.01854	20	0.99	0.63	0.03696	50	0.975	0.185	0.0555	700	0.65	0.0734	0.5000	0.8652	
	Outcome 16	0.63	0.01854	20	0.99	0.185	0.03696	100	0.95	0.185	0.0555	50	0.975	0.0216	0.5171	0.8750	
	Outcome 17	0.63	0.01854	20	0.99	0.185	0.03696	100	0.95	0.63	0.0555	500	0.75	0.0734	0.5046	0.8679	
	Outcome 18	0.63	0.01854	20	0.99	0.185	0.03696	100	0.95	0.185	0.0555	700	0.65	0.0216	0.4991	0.8646	
	Outcome 19	0.185	0.01854	20	0.99	0.185	0.03696	20	0.99	0.185	0.0555	50	0.975	0.0063	0.5186	0.8758	
	Outcome 20	0.185	0.01854	50	0.975	0.185	0.03696	20	0.99	0.63	0.0555	500	0.75	0.0216	0.5058	0.8686	
	Outcome 21	0.185	0.01854	50	0.975	0.185	0.03696	20	0.99	0.185	0.0555	700	0.65	0.0063	0.5003	0.8653	
	Outcome 22	0.185	0.01854	50	0.975	0.63	0.03696	50	0.975	0.185	0.0555	50	0.975	0.0216	0.5178	0.8754	
	Outcome 23	0.185	0.01854	50	0.975	0.63	0.03696	50	0.975	0.63	0.0555	500	0.75	0.0734	0.5053	0.8683	
	Outcome 24	0.185	0.01854	50	0.975	0.63	0.03696	50	0.975	0.185	0.0555	700	0.65	0.0216	0.4997	0.8650	
	Outcome 25	0.185	0.01854	50	0.975	0.185	0.03696	100	0.95	0.185	0.0555	50	0.975	0.0063	0.5169	0.8749	
	Outcome 26	0.185	0.01854	50	0.975	0.185	0.03696	100	0.95	0.63	0.0555	500	0.75	0.0216	0.5044	0.8677	
	Outcome 27	0.185	0.01854	50	0.975	0.185	0.03696	100	0.95	0.185	0.0555	700	0.65	0.0063	0.4988	0.8644	

E(U) Data for Q-Factors: DoD – E(U) Calculations

R=	0.269	DoD				PM				Base				Total	Value of	Utility of	EU of
Alternative		**Prob.**	**Weight**	**Score (X)**	**V**	**P**	**W**	**X**	**V**	**P**	**W**	**X**	**V**	Prob.	Outcome	Outcome	Alt
Q-Factors	Outcome 1	0.185	0.01854	10	0.995	0.185	0.03696	20	0.99	0.185	0.0555	1500	0.25	0.0063	0.6462	0.9321	
	Outcome 2	0.185	0.01854	10	0.995	0.185	0.03696	20	0.99	0.63	0.0555	1700	0.15	0.0216	0.6407	0.9302	
	Outcome 3	0.185	0.01854	10	0.995	0.185	0.03696	20	0.99	0.185	0.0555	2000	0	0.0063	0.6324	0.9272	
	Outcome 4	0.185	0.01854	10	0.995	0.63	0.03696	50	0.975	0.185	0.0555	1500	0.25	0.0216	0.6457	0.9320	
	Outcome 5	0.185	0.01854	10	0.995	0.63	0.03696	50	0.975	0.63	0.0555	1700	0.15	0.0734	0.6401	0.9300	
	Outcome 6	0.185	0.01854	10	0.995	0.63	0.03696	50	0.975	0.185	0.0555	2000	0	0.0216	0.6318	0.9270	
	Outcome 7	0.185	0.01854	10	0.995	0.185	0.03696	100	0.95	0.185	0.0555	1500	0.25	0.0063	0.6448	0.9316	
	Outcome 8	0.185	0.01854	10	0.995	0.185	0.03696	100	0.95	0.63	0.0555	1700	0.15	0.0216	0.6392	0.9297	
	Outcome 9	0.185	0.01854	10	0.995	0.185	0.03696	100	0.95	0.185	0.0555	2000	0	0.0063	0.6309	0.9267	
	Outcome 10	0.63	0.01854	20	0.99	0.185	0.03696	20	0.99	0.185	0.0555	1500	0.25	0.0216	0.6461	0.9321	
	Outcome 11	0.63	0.01854	20	0.99	0.185	0.03696	20	0.99	0.63	0.0555	1700	0.15	0.0734	0.6406	0.9302	
	Outcome 12	0.63	0.01854	20	0.99	0.185	0.03696	20	0.99	0.185	0.0555	2000	0	0.0216	0.6323	0.9272	
	Outcome 13	0.63	0.01854	20	0.99	0.63	0.03696	50	0.975	0.185	0.0555	1500	0.25	0.0734	0.6456	0.9319	
	Outcome 14	0.63	0.01854	20	0.99	0.63	0.03696	50	0.975	0.63	0.0555	1700	0.15	0.2500	0.6400	0.9300	0.9297
	Outcome 15	0.63	0.01854	20	0.99	0.63	0.03696	50	0.975	0.185	0.0555	2000	0	0.0734	0.6317	0.9270	
	Outcome 16	0.63	0.01854	20	0.99	0.185	0.03696	100	0.95	0.185	0.0555	1500	0.25	0.0216	0.6447	0.9316	
	Outcome 17	0.63	0.01854	20	0.99	0.185	0.03696	100	0.95	0.63	0.0555	1700	0.15	0.0734	0.6391	0.9297	
	Outcome 18	0.63	0.01854	20	0.99	0.185	0.03696	100	0.95	0.185	0.0555	2000	0	0.0216	0.6308	0.9267	
	Outcome 19	0.185	0.01854	50	0.975	0.185	0.03696	20	0.99	0.185	0.0555	1500	0.25	0.0063	0.6459	0.9320	
	Outcome 20	0.185	0.01854	50	0.975	0.185	0.03696	20	0.99	0.63	0.0555	1700	0.15	0.0216	0.6403	0.9301	
	Outcome 21	0.185	0.01854	50	0.975	0.185	0.03696	20	0.99	0.185	0.0555	2000	0	0.0063	0.6320	0.9271	
	Outcome 22	0.185	0.01854	50	0.975	0.63	0.03696	50	0.975	0.185	0.0555	1500	0.25	0.0216	0.6453	0.9318	
	Outcome 23	0.185	0.01854	50	0.975	0.63	0.03696	50	0.975	0.63	0.0555	1700	0.15	0.0734	0.6398	0.9299	
	Outcome 24	0.185	0.01854	50	0.975	0.63	0.03696	50	0.975	0.185	0.0555	2000	0	0.0216	0.6314	0.9269	
	Outcome 25	0.185	0.01854	50	0.975	0.185	0.03696	100	0.95	0.185	0.0555	1500	0.25	0.0063	0.6444	0.9315	
	Outcome 26	0.185	0.01854	50	0.975	0.185	0.03696	100	0.95	0.63	0.0555	1700	0.15	0.0216	0.6388	0.9296	
	Outcome 27	0.185	0.01854	50	0.975	0.185	0.03696	100	0.95	0.185	0.0555	2000	0	0.0063	0.6305	0.9266	

E(U) Data for Alt FRM: DoD – E(U) Calculations

R=	0.269	**DoD**				**PM**				**Base**				Total	Value of	Utility of	EU of
	Alternative	**Prob.**	**Weight**	**Score (X)**	**V**	**P**	**W**	**X**	**V**	**P**	**W**	**X**	**V**	Prob.	Outcome	Outcome	Alt
Alt	Outcome 1	0.185	0.01854	100	0.95	0.185	0.03696	200	0.9	0.185	0.0555	30	0.985	0.0063	0.6577	0.9360	
FRM	Outcome 2	0.185	0.01854	100	0.95	0.185	0.03696	200	0.9	0.63	0.0555	50	0.975	0.0216	0.6571	0.9358	
	Outcome 3	0.185	0.01854	100	0.95	0.185	0.03696	200	0.9	0.185	0.0555	70	0.965	0.0063	0.6566	0.9356	
	Outcome 4	0.185	0.01854	100	0.95	0.63	0.03696	250	0.875	0.185	0.0555	30	0.985	0.0216	0.6568	0.9357	
	Outcome 5	0.185	0.01854	100	0.95	0.63	0.03696	250	0.875	0.63	0.0555	50	0.975	0.0734	0.6562	0.9355	
	Outcome 6	0.185	0.01854	100	0.95	0.63	0.03696	250	0.875	0.185	0.0555	70	0.965	0.0216	0.6557	0.9353	
	Outcome 7	0.185	0.01854	100	0.95	0.185	0.03696	400	0.8	0.185	0.0555	30	0.985	0.0063	0.6540	0.9348	
	Outcome 8	0.185	0.01854	100	0.95	0.185	0.03696	400	0.8	0.63	0.0555	50	0.975	0.0216	0.6534	0.9346	
	Outcome 9	0.185	0.01854	100	0.95	0.185	0.03696	400	0.8	0.185	0.0555	70	0.965	0.0063	0.6529	0.9344	
	Outcome 10	0.63	0.01854	150	0.925	0.185	0.03696	200	0.9	0.185	0.0555	30	0.985	0.0216	0.6572	0.9359	
	Outcome 11	0.63	0.01854	150	0.925	0.185	0.03696	200	0.9	0.63	0.0555	50	0.975	0.0734	0.6567	0.9357	
	Outcome 12	0.63	0.01854	150	0.925	0.185	0.03696	200	0.9	0.185	0.0555	70	0.965	0.0216	0.6561	0.9355	
	Outcome 13	0.63	0.01854	150	0.925	0.63	0.03696	250	0.875	0.185	0.0555	30	0.985	0.0734	0.6563	0.9356	
	Outcome 14	0.63	0.01854	150	0.925	0.63	0.03696	250	0.875	0.63	0.0555	50	0.975	0.2500	0.6558	0.9354	0.9352
	Outcome 15	0.63	0.01854	150	0.925	0.63	0.03696	250	0.875	0.185	0.0555	70	0.965	0.0734	0.6552	0.9352	
	Outcome 16	0.63	0.01854	150	0.925	0.185	0.03696	400	0.8	0.185	0.0555	30	0.985	0.0216	0.6535	0.9346	
	Outcome 17	0.63	0.01854	150	0.925	0.185	0.03696	400	0.8	0.63	0.0555	50	0.975	0.0734	0.6530	0.9344	
	Outcome 18	0.63	0.01854	150	0.925	0.185	0.03696	400	0.8	0.185	0.0555	70	0.965	0.0216	0.6524	0.9343	
	Outcome 19	0.185	0.01854	300	0.85	0.185	0.03696	200	0.9	0.185	0.0555	30	0.985	0.0063	0.6558	0.9354	
	Outcome 20	0.185	0.01854	300	0.85	0.185	0.03696	200	0.9	0.63	0.0555	50	0.975	0.0216	0.6553	0.9352	
	Outcome 21	0.185	0.01854	300	0.85	0.185	0.03696	200	0.9	0.185	0.0555	70	0.965	0.0063	0.6547	0.9350	
	Outcome 22	0.185	0.01854	300	0.85	0.63	0.03696	250	0.875	0.185	0.0555	30	0.985	0.0216	0.6549	0.9351	
	Outcome 23	0.185	0.01854	300	0.85	0.63	0.03696	250	0.875	0.63	0.0555	50	0.975	0.0734	0.6544	0.9349	
	Outcome 24	0.185	0.01854	300	0.85	0.63	0.03696	250	0.875	0.185	0.0555	70	0.965	0.0216	0.6538	0.9347	
	Outcome 25	0.185	0.01854	300	0.85	0.185	0.03696	400	0.8	0.185	0.0555	30	0.985	0.0063	0.6521	0.9342	
	Outcome 26	0.185	0.01854	300	0.85	0.185	0.03696	400	0.8	0.63	0.0555	50	0.975	0.0216	0.6516	0.9340	
	Outcome 27	0.185	0.01854	300	0.85	0.185	0.03696	400	0.8	0.185	0.0555	70	0.965	0.0063	0.6510	0.9338	

E(U) Data for Alt FMM: DoD – E(U) Calculations

R=	0.269	DoD				PM				Base				Total	Value of	Utility of	EU
Alternative		**Prob.**	**Weight**	**Score (X)**	**V**	**P**	**W**	**X**	**V**	**P**	**W**	**X**	**V**	Prob.	Outcome	Outcome	Of Alt
Alt FMM	Outcome 1	0.185	0.01854	50	0.975	0.185	0.03696	200	0.9	0.185	0.0555	10	0.995	0.0063	0.7206	0.9545	
	Outcome 2	0.185	0.01854	50	0.975	0.185	0.03696	200	0.9	0.63	0.0555	50	0.975	0.0216	0.7195	0.9542	
	Outcome 3	0.185	0.01854	50	0.975	0.185	0.03696	200	0.9	0.185	0.0555	90	0.955	0.0063	0.7184	0.9540	
	Outcome 4	0.185	0.01854	50	0.975	0.63	0.03696	250	0.875	0.185	0.0555	10	0.995	0.0216	0.7197	0.9543	
	Outcome 5	0.185	0.01854	50	0.975	0.63	0.03696	250	0.875	0.63	0.0555	50	0.975	0.0734	0.7185	0.9540	
	Outcome 6	0.185	0.01854	50	0.975	0.63	0.03696	250	0.875	0.185	0.0555	90	0.955	0.0216	0.7174	0.9537	
	Outcome 7	0.185	0.01854	50	0.975	0.185	0.03696	300	0.85	0.185	0.0555	10	0.995	0.0063	0.7187	0.9541	
	Outcome 8	0.185	0.01854	50	0.975	0.185	0.03696	300	0.85	0.63	0.0555	50	0.975	0.0216	0.7176	0.9538	
	Outcome 9	0.185	0.01854	50	0.975	0.185	0.03696	300	0.85	0.185	0.0555	90	0.955	0.0063	0.7165	0.9535	
	Outcome 10	0.63	0.01854	150	0.925	0.185	0.03696	200	0.9	0.185	0.0555	10	0.995	0.0216	0.7197	0.9543	
	Outcome 11	0.63	0.01854	150	0.925	0.185	0.03696	200	0.9	0.63	0.0555	50	0.975	0.0734	0.7185	0.9540	
	Outcome 12	0.63	0.01854	150	0.925	0.185	0.03696	200	0.9	0.185	0.0555	90	0.955	0.0216	0.7174	0.9537	
	Outcome 13	0.63	0.01854	150	0.925	0.63	0.03696	250	0.875	0.185	0.0555	10	0.995	0.0734	0.7187	0.9541	
	Outcome 14	0.63	0.01854	150	0.925	0.63	0.03696	250	0.875	0.63	0.0555	50	0.975	0.2500	0.7176	0.9538	0.9538
	Outcome 15	0.63	0.01854	150	0.925	0.63	0.03696	250	0.875	0.185	0.0555	90	0.955	0.0734	0.7165	0.9535	
	Outcome 16	0.63	0.01854	150	0.925	0.185	0.03696	300	0.85	0.185	0.0555	10	0.995	0.0216	0.7178	0.9538	
	Outcome 17	0.63	0.01854	150	0.925	0.185	0.03696	300	0.85	0.63	0.0555	50	0.975	0.0734	0.7167	0.9535	
	Outcome 18	0.63	0.01854	150	0.925	0.185	0.03696	300	0.85	0.185	0.0555	90	0.955	0.0216	0.7156	0.9532	
	Outcome 19	0.185	0.01854	200	0.9	0.185	0.03696	200	0.9	0.185	0.0555	10	0.995	0.0063	0.7192	0.9542	
	Outcome 20	0.185	0.01854	200	0.9	0.185	0.03696	200	0.9	0.63	0.0555	50	0.975	0.0216	0.7181	0.9539	
	Outcome 21	0.185	0.01854	200	0.9	0.185	0.03696	200	0.9	0.185	0.0555	90	0.955	0.0063	0.7170	0.9536	
	Outcome 22	0.185	0.01854	200	0.9	0.63	0.03696	250	0.875	0.185	0.0555	10	0.995	0.0216	0.7183	0.9539	
	Outcome 23	0.185	0.01854	200	0.9	0.63	0.03696	250	0.875	0.63	0.0555	50	0.975	0.0734	0.7172	0.9536	
	Outcome 24	0.185	0.01854	200	0.9	0.63	0.03696	250	0.875	0.185	0.0555	90	0.955	0.0216	0.7160	0.9533	
	Outcome 25	0.185	0.01854	200	0.9	0.185	0.03696	300	0.85	0.185	0.0555	10	0.995	0.0063	0.7173	0.9537	
	Outcome 26	0.185	0.01854	200	0.9	0.185	0.03696	300	0.85	0.63	0.0555	50	0.975	0.0216	0.7162	0.9534	
	Outcome 27	0.185	0.01854	200	0.9	0.185	0.03696	300	0.85	0.185	0.0555	90	0.955	0.0063	0.7151	0.9531	

E(U) Data for H-Model: DoD – E(U) Calculations

R=	0.269	DoD				PM				Base				Total	Value of	Utility of	EU of
Alternative		Prob.	Weight	Score (X)	Value	P	W	X	V	P	W	X	V	Prob.	Outcome	Outcome	Alt
H-Model	Outcome 1	0.185	0.01854	500	0.75	0.185	0.03696	500	0.75	0.185	0.0555	1500	0.25	0.0063	0.8059	0.9737	
	Outcome 2	0.185	0.01854	500	0.75	0.185	0.03696	500	0.75	0.63	0.0555	1700	0.15	0.0216	0.8004	0.9726	
	Outcome 3	0.185	0.01854	500	0.75	0.185	0.03696	500	0.75	0.185	0.0555	2000	0	0.0063	0.7921	0.9710	
	Outcome 4	0.185	0.01854	500	0.75	0.63	0.03696	1000	0.5	0.185	0.0555	1500	0.25	0.0216	0.7967	0.9719	
	Outcome 5	0.185	0.01854	500	0.75	0.63	0.03696	1000	0.5	0.63	0.0555	1700	0.15	0.0734	0.7911	0.9708	
	Outcome 6	0.185	0.01854	500	0.75	0.63	0.03696	1000	0.5	0.185	0.0555	2000	0	0.0216	0.7828	0.9691	
	Outcome 7	0.185	0.01854	500	0.75	0.185	0.03696	1500	0.25	0.185	0.0555	1500	0.25	0.0063	0.7875	0.9700	
	Outcome 8	0.185	0.01854	500	0.75	0.185	0.03696	1500	0.25	0.63	0.0555	1700	0.15	0.0216	0.7819	0.9689	
	Outcome 9	0.185	0.01854	500	0.75	0.185	0.03696	1500	0.25	0.185	0.0555	2000	0	0.0063	0.7736	0.9671	
	Outcome 10	0.63	0.01854	1000	0.5	0.185	0.03696	500	0.75	0.185	0.0555	1500	0.25	0.0216	0.8013	0.9728	
	Outcome 11	0.63	0.01854	1000	0.5	0.185	0.03696	500	0.75	0.63	0.0555	1700	0.15	0.0734	0.7958	0.9717	
	Outcome 12	0.63	0.01854	1000	0.5	0.185	0.03696	500	0.75	0.185	0.0555	2000	0	0.0216	0.7874	0.9700	
	Outcome 13	0.63	0.01854	1000	0.5	0.63	0.03696	1000	0.5	0.185	0.0555	1500	0.25	0.0734	0.7921	0.9710	
	Outcome 14	0.63	0.01854	1000	0.5	0.63	0.03696	1000	0.5	0.63	0.0555	1700	0.15	0.2500	0.7865	0.9698	0.9697
	Outcome 15	0.63	0.01854	1000	0.5	0.63	0.03696	1000	0.5	0.185	0.0555	2000	0	0.0734	0.7782	0.9681	
	Outcome 16	0.63	0.01854	1000	0.5	0.185	0.03696	1500	0.25	0.185	0.0555	1500	0.25	0.0216	0.7828	0.9691	
	Outcome 17	0.63	0.01854	1000	0.5	0.185	0.03696	1500	0.25	0.63	0.0555	1700	0.15	0.0734	0.7773	0.9679	
	Outcome 18	0.63	0.01854	1000	0.5	0.185	0.03696	1500	0.25	0.185	0.0555	2000	0	0.0216	0.7689	0.9661	
	Outcome 19	0.185	0.01854	1500	0.25	0.185	0.03696	500	0.75	0.185	0.0555	1500	0.25	0.0063	0.7967	0.9719	
	Outcome 20	0.185	0.01854	1500	0.25	0.185	0.03696	500	0.75	0.63	0.0555	1700	0.15	0.0216	0.7911	0.9708	
	Outcome 21	0.185	0.01854	1500	0.25	0.185	0.03696	500	0.75	0.185	0.0555	2000	0	0.0063	0.7828	0.9691	
	Outcome 22	0.185	0.01854	1500	0.25	0.63	0.03696	1000	0.5	0.185	0.0555	1500	0.25	0.0216	0.7874	0.9700	
	Outcome 23	0.185	0.01854	1500	0.25	0.63	0.03696	1000	0.5	0.63	0.0555	1700	0.15	0.0734	0.7819	0.9689	
	Outcome 24	0.185	0.01854	1500	0.25	0.63	0.03696	1000	0.5	0.185	0.0555	2000	0	0.0216	0.7736	0.9671	
	Outcome 25	0.185	0.01854	1500	0.25	0.185	0.03696	1500	0.25	0.185	0.0555	1500	0.25	0.0063	0.7782	0.9681	
	Outcome 26	0.185	0.01854	1500	0.25	0.185	0.03696	1500	0.25	0.63	0.0555	1700	0.15	0.0216	0.7726	0.9669	
	Outcome 27	0.185	0.01854	1500	0.25	0.185	0.03696	1500	0.25	0.185	0.0555	2000	0	0.0063	0.7643	0.9651	

Appendix F – Certainty Equivalent

Certainty equivalent is a method of determining the best decision among multiple alternatives, while considering the decision-makers risk behavior. As defined by Kirkwood (1997), "The certainty equivalent for an (uncertain) alternative is the certain level of the evaluation measures that is equally preferred to the (gamble from Figure 10)." Otherwise stated, it is the total value of an alternative that would make the decision-maker indifferent between the alternative and the lottery. If there is no uncertainty in the evaluation measure the CE is simply the expected value (value times weight). First, a CE value must be calculated for each evaluation measure under each alternative. This is done using the formula (adapted from Kirkwood, 1997):

$$V_{ce} = -\rho_m * \ln [E (e^{[(-wi)(V(xi))/(\rho m)]})] \tag{19}$$

where

V_{ce} = certainty equivalent for evaluation measure i

ρ_m = multi-attribute risk tolerance

W_i = weight of value at evaluation measure i

$V(X_i)$= value of outcome at evaluation measure i

Once all evaluation measure CEs are found, the total alternative CE value is calculated using the following equation (adapted from Kirkwood, 1997):

$$V_{CEj} = \sum (V_{CEji}) \tag{20}$$

where

V_{CEj} = value of the certainty equivalent for alternative j

V_{CEji} = value of the certainty equivalent for alternative j and evaluation measure i

Once the certainty equivalents are calculated for each alternative, then they can be ranked to determine preferential order. Sensitivity analysis is then performed to determine if the solution was sensitive to the value of ρ_m by varying ρ_m from -0.1 to 0.1 and recalculating the CE values to see if the ranked order of alternative changes. If there is no change in the ranked order then the decision is not dependent on the decision-maker's risk behavior.

To calculate the CE for each alternative, probabilistic independence must be assumed. This means that the "probability distribution for any evaluation measure does not change for different levels of other evaluation measures" (Kirkwood, 97). Once this is assumed, the CE for each alternative is calculated by adding the individual CE scores for each evaluation measure. A summary of the ranked results from the CE calculations in comparison to the deterministic, expected value (EV), and expected utility (E(U)) rankings is shown in Table 14.

Table 14. Summary of CE Analysis Rankings

	Deterministic Analysis		Probabilistic Analyses					
	Value Analysis		Expected Value Analysis		Expected Utility Analysis		Certainty Equivalent Analysis	
Rank	**Alternative**	**Value**	**Alternative**	**EV**	**Alt**	**EU**	**Alt**	**CE**
1	*H-Model*	0.7865	*H-Model*	0.7860	*H-Model*	0.9697	*H-Model*	0.7859
2	*Alt FMM*	0.7176	*Alt FMM*	0.7177	*Alt FMM*	0.9538	*Alt FMM*	0.7177
3	*FMM*	0.6899	*FMM*	0.6900	*FMM*	0.9461	*FMM*	0.6900
4	*Dep*	0.6653	*Dep*	0.6648	*Dep*	0.9383	*Dep*	0.6648
5	*Alt FRM*	0.6558	*Alt FRM*	0.6552	*Alt FRM*	0.9352	*Alt FRM*	0.6552
6	*PRV*	0.6504	*PRV*	0.6503	*PRV*	0.9336	*PRV*	0.6504
7	*Q Fact*	0.6400	*Q Fact*	0.6394	*Q Fact*	0.9297	*Q Fact*	0.6394
8	*FRM*	0.5964	*FRM*	0.5964	*FRM*	0.9132	*FRM*	0.5963
9	*AME*	0.5894	*AME*	0.5889	*AME*	0.9100	*AME*	0.5888
10	*BUILDER*	0.5343	*BUILDER*	0.5338	*BUILDER*	0.8840	*BUILDER*	0.5337
11	*Bottom Up*	0.4989	*Bottom Up*	0.5001	*Bottom Up*	0.8691	*Bottom Up*	0.5000
12	*Fac Ren*	0.4044	*Fac Ren*	0.4051	*Fac Ren*	0.7975	*Fac Ren*	0.4050
13	*Dergis Sherman*	0.4013	*Dergis Sherman*	0.4013	*Dergis Sherman*	0.7943	*Dergis Sherman*	0.4012
14	*CPV*	0.3942	*CPV*	0.3942	*CPV*	0.7880	*CPV*	0.3941
15	*Renewal Fact*	0.3876	*Renewal Fact*	0.3871	*Renewal Fact*	0.7817	*Renewal Fact*	0.3870

Conceptually, the CE for an alternative is the total value that the alternative would need to score for the DM to be indifferent between the alternative and the gamble. For any evaluation measures without uncertainty, the CE is simply the value of the evaluation measure calculated by multiplying the weight by the value. Another concept that ties into CE is the risk premium, which is calculated by subtracting CE from EV. The risk premium is the amount of value that the DM would theoretically be willing to give up to avoid choosing the lottery. A positive risk premium value means that the DM would be willing to sacrifice some value to not take the gamble. A negative risk premium value means that the DM would prefer to take the gamble. A

summary of the risk premium values for each alternative is shown in Table 15. A graphical representation of the relationship between E(U), CE, Expected Value (EV), and risk premium is shown in Figure 29.

Table 15. Summary of Risk Premium Values

	Deterministic Analysis		**Probabilistic Analyses**						
	Value Analysis		**Expected Value Analysis**		**Expected Utility Analysis**		**Certainty Equivalent Analysis**		**Risk Premium**
Rank	**Alternative**	**Value**	**Alt**	**Expected Value**	**Alt**	**EU**	**Alt**	**CE**	**EV-CE**
1	*H-Model*	0.7865	*H-Model*	0.7860	*H-Model*	0.9697	*H-Model*	0.7859	0.0001
2	*Alt FMM*	0.7176	*Alt FMM*	0.7177	*Alt FMM*	0.9538	*Alt FMM*	0.7177	0.0000
3	*FMM*	0.6899	*FMM*	0.6900	*FMM*	0.9461	*FMM*	0.6900	0.0000
4	*Dep*	0.6653	*Dep*	0.6648	*Dep*	0.9383	*Dep*	0.6648	0.0000
5	*Alt FRM*	0.6558	*Alt FRM*	0.6552	*Alt FRM*	0.9352	*Alt FRM*	0.6552	0.0000
6	*PRV*	0.6504	*PRV*	0.6503	*PRV*	0.9336	*PRV*	0.6504	0.0000
7	*Q Fact*	0.6400	*Q Fact*	0.6394	*Q Fact*	0.9297	*Q Fact*	0.6394	0.0001
8	*FRM*	0.5964	*FRM*	0.5964	*FRM*	0.9132	*FRM*	0.5963	0.0000
9	*AME*	0.5894	*AME*	0.5889	*AME*	0.9100	*AME*	0.5887	0.0002
10	*BUILDER*	0.5343	*BUILDER*	0.5338	*BUILDER*	0.8840	*BUILDER*	0.5337	0.0001
11	*Bottom Up*	0.4989	*Bottom Up*	0.5001	*Bottom Up*	0.8691	*Bottom Up*	0.5000	0.0000
12	*Fac Ren*	0.4044	*Fac Ren*	0.4051	*Fac Ren*	0.7975	*Fac Ren*	0.4050	0.0001
13	*Dergis Sherman*	0.4013	*Dergis Sherman*	0.4013	*Dergis Sherman*	0.7943	*Dergis Sherman*	0.4012	0.0000
14	*CPV*	0.3942	*CPV*	0.3942	*CPV*	0.7880	*CPV*	0.3941	0.0000
15	*Renewal Fact*	0.3876	*Renewal Fact*	0.3871	*Renewal Fact*	0.7817	*Renewal Fact*	0.3869	0.0002

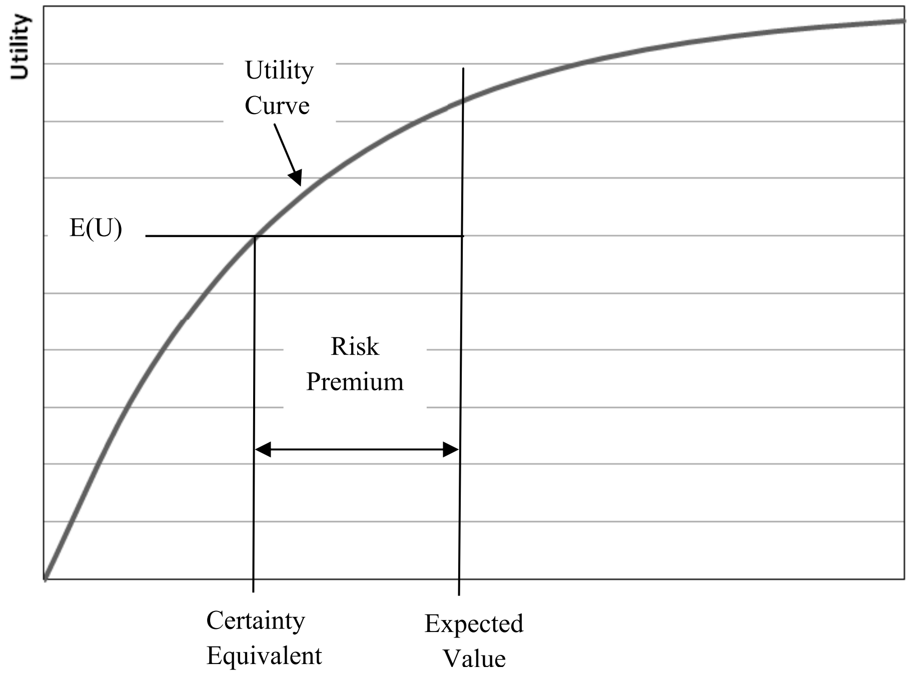


Figure 29. Graphical Representation of Risk Premium (Adapted from Clemen and Reilly, 2001)

Similar to the expected utility analysis (E(U)), a sensitivity analysis is performed on ρ_m to determine if the CE is sensitive to the decision-maker's risk behavior. The ρ_m is varied from -.5 to .5 and the results are shown in Table 16. The ranked order of alternatives remains the same across all values of ρ_m, meaning that risk has no bearing on the CE analysis results.

Table 16. Sensitivity Analysis of ρ_m on CE

ρ_m =	0.269		Risk Seeking		Risk Neutral	Risk Averse	
Alternative	CE		ρ_m = -.1	ρ_m =-0.5	ρ_m =10	ρ_m =0.5	ρ_m =.1
H-Model	0.7860		0.7863	0.7860	0.7860	0.7859	0.7857
Alt FMM	0.7177		0.7177	0.7177	0.7177	0.7177	0.7177
FMM	0.6900		0.6900	0.6900	0.6900	0.6900	0.6900
Dep	0.6648		0.6649	0.6648	0.6648	0.6648	0.6647
Alt FRM	0.6552		0.6552	0.6552	0.6552	0.6552	0.6552
PRV	0.6504		0.6504	0.6504	0.6504	0.6504	0.6504
Q Fact	0.6394		0.6395	0.6394	0.6394	0.6394	0.6393
FRM	0.5964		0.5964	0.5964	0.5964	0.5963	0.5963
AME	0.5890		0.5893	0.5890	0.5889	0.5888	0.5885
BUILDER	0.5339		0.5341	0.5339	0.5338	0.5337	0.5335
Bottom Up	0.5001		0.5003	0.5001	0.5001	0.5000	0.4999
Fac Ren	0.4051		0.4052	0.4051	0.4051	0.4051	0.4050
Dergis Sherman	0.4013		0.4014	0.4013	0.4013	0.4013	0.4012
CPV	0.3942		0.3943	0.3942	0.3942	0.3941	0.3940
Renewal Fact	0.3871		0.3874	0.3871	0.3871	0.3870	0.3867

As described in the E(U) analysis section of the thesis, an increase in the weight of Implementation to .333 caused changes to alternative rankings. To further illustrate that the E(U) rankings match the CE rankings, Table 17 is provided below to summarize the CE results as compared to the other analyses.

Table 17. Summary of Analyses for Increased Weight of *Implementation*

	Deterministic Analysis		**Probabilistic Analyses**					
	Value Analysis		**Expected Value Analysis**		**Expected Utility Analysis**		**Certainty Equivalent Analysis**	
Rank	**Alternative**	**Value**	**Alternative**	**Expected Value**	**Alt**	**EU**	**Alt**	**CE**
1	*Alt FMM*	0.7241	*Alt FMM*	0.7242	*Alt FMM*	0.9667	*Alt FMM*	0.7717
2	*FMM*	0.7031	*FMM*	0.7032	*FMM*	0.9620	*FMM*	0.7509
3	*Alt FRM*	0.6789	*Alt FRM*	0.6778	*Alt FRM*	0.9553	*Alt FRM*	0.7234
4	*PRV*	0.6549	*PRV*	0.6548	*PRV*	0.9474	*PRV*	0.6946
5	*Depreciation*	0.6506	*Depreciation*	0.6505	*FRM*	0.9447	*FRM*	0.6853
6	*H-Model*	0.6446	*H Model*	0.6431	*Depreciation*	0.9416	*Depreciation*	0.6751
7	*FRM*	0.6381	*FRM*	0.6381	*H-Model*	0.9396	*H-Model*	0.6687
8	*Q Factors*	0.5703	*Q Factors*	0.5685	*Q Factors*	0.9223	*Q Factors*	0.6191
9	*Bottom Up*	0.5391	*Bottom Up*	0.5427	*Bottom Up*	0.9141	*Bottom Up*	0.5984
10	*AME*	0.5298	*AME*	0.5287	*AME*	0.8990	*AME*	0.5641
11	*BUILDER*	0.4573	*BUILDER*	0.4557	*BUILDER*	0.8525	*BUILDER*	0.4795
12	*Dergis Sherman*	0.4374	*Dergis Sherman*	0.4374	*Dergis Sherman*	0.8444	*Dergis Sherman*	0.4672
13	*CPV*	0.4321	*CPV*	0.4321	*CPV*	0.8407	*CPV*	0.4617
14	*Fac Ren*	0.4294	*Fac Ren*	0.4314	*Fac Ren*	0.8403	*Fac Ren*	0.4610
15	*Renewal Fact*	0.4094	*Renewal Fact*	0.4084	*Renewal Fact*	0.8283	*Renewal Fact*	0.4441

CE Data for All Alternatives: EMs Planning Horizon - # Fac Types

	Planning Horizon			% Condition			% Life-Cycle			Emp. Support			Sensitivity			Comprehension		
Alternative	**Weight**	**Score (X)**	**Value**	**W**	**X**	**V**	**W**	**X**	**V**	**W**	**X**	**V**	**W**	**X**	**V**	**W**	**X**	**V**
CPV	0.1665	2	0.333	0.0444	0	0	0.0388	0	0	0.0277	No	0	0.0556	Low	0	0.2224	Med	0.67
CE of EM	0.0555			0.0000			0.0000			0.0000			0.0000			0.1490		
PRV	0.1665	5	0.75	0.0444	0	0	0.0388	0	0	0.0277	Yes	1	0.0556	Low	0	0.2224	High	1
CE of EM	0.1249			0.0000			0.0000			0.0277			0.0000			0.2224		
Dergis-Sher	0.1665	2	0.333	0.0444	0	0	0.0388	0	0	0.0277	No	0	0.0556	Low	0	0.2224	Med	0.67
CE of EM	0.0554			0.0000			0.0000			0.0000			0.0000			0.1490		
Fac. Renewal	0.1665	2	0.333	0.0444	0	0	0.0388	20	0.2	0.0277	No	0	0.0556	Low	0	0.2224	Med	0.67
CE of EM	0.0554			0.0000			0.0078			0.0000			0.0000			0.1490		
Depreciation	0.1665	30	1	0.0444	0	0	0.0388	0	0	0.0277	No	0	0.0556	Med	0.67	0.2224	Med	0.67
CE of EM	0.1665			0.0000			0.0000			0.0000			0.0373			0.1490		
BUILDER	0.1665	30	1	0.0444	50	0.5	0.0388	50	0.5	0.0277	Yes	1	0.0556	Low	0	0.2224	Med	0.67
CE of EM	0.1665			0.0222			0.0194			0.0277			0.0000			0.1490		
Renewal Fact.	0.1665	30	1	0.0444	0	0	0.0388	70	0.7	0.0277	No	0	0.0556	Low	0	0.2224	Low	0
CE of EM	0.1665			0.0000			0.0272			0.0000			0.0000			0.0000		
AME	0.1665	5	0.75	0.0444	50	0.5	0.0388	50	0.5	0.0277	Yes	1	0.0556	Low	0	0.2224	High	1
CE of EM	0.1249			0.0222			0.0194			0.0277			0.0000			0.2224		
FRM	0.1665	5	0.75	0.0444	0	0	0.0388	0	0	0.0277	Yes	1	0.0556	Low	0	0.2224	Med	0.67
CE of EM	0.1249			0.0000			0.0000			0.0277			0.0000			0.1490		
FMM	0.1665	30	1	0.0444	0	0	0.0388	0	0	0.0277	No	0	0.0556	Med	0.67	0.2224	Med	0.67
CE of EM	0.1665			0.0000			0.0000			0.0000			0.0373			0.1490		
Bottom Up	0.1665	5	0.75	0.0444	0	0	0.0388	0	0	0.0277	No	0	0.0556	High	1	0.2224	High	1
CE of EM	0.1249			0.0000			0.0000			0.0000			0.0556			0.2224		
Q-Factors	0.1665	5	0.75	0.0444	75	0.75	0.0388	0	0	0.0277	Yes	1	0.0556	High	1	0.2224	High	1
CE of EM	0.1249			0.0333			0.0000			0.0277			0.0556			0.2224		
Alt FRM	0.1665	5	0.75	0.0444	0	0	0.0388	0	0	0.0277	Yes	1	0.0556	Low	0	0.2224	Med	0.67
CE of EM	0.1249			0.0000			0.0000			0.0277			0.0000			0.1490		
Alt FMM	0.1665	30	1	0.0444	0	0	0.0388	0	0	0.0277	Yes	1	0.0556	Med	0.67	0.2224	Med	0.67
CE of EM	0.1665			0.0000			0.0000			0.0277			0.0373			0.1490		
H-Model	0.1665	30	1	0.0444	50	0.5	0.0388	25	0.25	0.0277	Yes	1	0.0556	High	1	0.2224	High	1
CE of EM	0.1665			0.0222			0.0097			0.0277			0.0556			0.2224		

CE Data for All Alternatives: EMs Type A - Consistency

	# Fac Types			Type A			Type B			Type C			Consistency		
Alternative	**Weight**	**Score (X)**	**Value**	**W**	**X**	**V**	**W**	**X**	**V**	**W**	**X**	**V**	**W**	**X**	**V**
CPV	0.1001	0	0	0.033	0	0	0.023	1	0.17	0.01	0	0	0.167	Med	0.67
CE of EM	0.0000			0.0000			0.0039			0.0000			0.1118		
PRV	0.1001	0	0	0.033	2	0.4	0.023	0	0	0.01	1	0.33	0.167	High	1
CE of EM	0.0000			0.0133			0.0000			0.0033			0.1668		
Dergis Sherman	0.1001	1	0.005	0.033	1	0.2	0.023	1	0.17	0.01	0	0	0.167	Med	0.67
CE of EM	0.0005			0.0067			0.0039			0.0000			0.1118		
Fac. Renewal	0.1001	1	0.005	0.033	1	0.2	0.023	1	0.17	0.01	0	0	0.167	Med	0.67
CE of EM	0.0005			0.0067			0.0039			0.0000			0.1118		
Depreciation	0.1001	100	0.5	0.033	2	0.4	0.023	0	0	0.01	1	0.33	0.167	High	1
CE of EM	0.0500			0.0133			0.0000			0.0033			0.1668		
BUILDER	0.1001	200	1	0.033	2	0.4	0.023	0	0	0.01	0	0	0.167	Low	0
CE of EM	0.1001			0.0133			0.0000			0.0000			0.0000		
Renewal Fact.	0.1001	200	1	0.033	2	0.4	0.023	2	0.33	0.01	1	0.33	0.167	Low	0
CE of EM	0.1001			0.0133			0.0078			0.0033			0.0000		
AME	0.1001	200	1	0.033	2	0.4	0.023	1	0.17	0.01	0	0	0.167	Low	0
CE of EM	0.1001			0.0133			0.0039			0.0000			0.0000		
FRM	0.1001	1	0.005	0.033	1	0.2	0.023	3	0.5	0.01	1	0.33	0.167	High	1
CE of EM	0.0005			0.0067			0.0117			0.0033			0.1668		
FMM	0.1001	70	0.35	0.033	2	0.4	0.023	3	0.5	0.01	2	0.67	0.167	High	1
CE of EM	0.0350			0.0133			0.0117			0.0067			0.1668		
Bottom Up	0.1001	0	0	0.033	0	0	0.023	0	0	0.01	0	0	0.167	Low	0
CE of EM	0.0000			0.0000			0.0000			0.0000			0.0000		
Q-Factors	0.1001	200	1	0.033	2	0.4	0.023	0	0	0.01	0	0	0.167	Low	0
CE of EM	0.1001			0.0133			0.0000			0.0000			0.0000		
Alt FRM	0.1001	124	0.62	0.033	1	0.2	0.023	3	0.5	0.01	1	0.33	0.167	High	1
CE of EM	0.0620			0.0067			0.0117			0.0033			0.1668		
Alt FMM	0.1001	70	0.35	0.033	2	0.4	0.023	3	0.5	0.01	2	0.67	0.167	High	1
CE of EM	0.0350			0.0133			0.0117			0.0067			0.1668		
H-Model	0.1001	200	1	0.033	4	0.8	0.023	2	0.33	0.01	0	0	0.167	Med	0.67
CE of EM	0.056			0.027			0.008			0.000			0.112		

CE Data for Alternatives 1 - 8: Uncertain EMs and CE of Alt

R= **0.269**		**DoD**				**PM**				**Base**				**CE of**
Alternative		**Prob.**	**Weight**	**Score (X)**	**Value**	**P**	**W**	**X**	**V**	**P**	**W**	**X**	**V**	**Alt**
1. CPV	Outcome 1	0.185	0.0185	600	0.7	0.185	0.037	600	0.7	0.185	0.06	300	0.85	
	Outcome 2	0.63	0.0185	800	0.6	0.63	0.037	1000	0.5	0.63	0.06	400	0.8	
	Outcome 3	0.185	0.0185	1000	0.5	0.185	0.037	1400	0.3	0.185	0.06	500	0.75	
CE of EM			0.0111				0.018				0.04			0.3941
2. PRV	Outcome 1	0.185	0.0185	300	0.85	0.185	0.037	700	0.65	0.185	0.06	0	1	
	Outcome 2	0.63	0.0185	400	0.8	0.63	0.037	800	0.6	0.63	0.06	20	0.99	
	Outcome 3	0.185	0.0185	500	0.75	0.185	0.037	900	0.55	0.185	0.06	50	0.975	
CE of EM			0.0148				0.022				0.05			0.6504
3. Dergis Sherman	Outcome 1	0.185	0.0185	600	0.7	0.185	0.037	800	0.6	0.185	0.06	200	0.9	
	Outcome 2	0.63	0.0185	800	0.6	0.63	0.037	1000	0.5	0.63	0.06	400	0.8	
	Outcome 3	0.185	0.0185	1000	0.5	0.185	0.037	1200	0.4	0.185	0.06	600	0.7	
CE of EM			0.0111				0.018				0.04			0.4012
4. Facilities	Outcome 1	0.185	0.0185	600	0.7	0.185	0.037	800	0.6	0.185	0.06	200	0.9	
Renewal	Outcome 2	0.63	0.0185	800	0.6	0.63	0.037	1250	0.375	0.63	0.06	400	0.8	
	Outcome 3	0.185	0.0185	1000	0.5	0.185	0.037	1500	0.25	0.185	0.06	600	0.7	
CE of EM			0.0111				0.015				0.04			0.4050
5. Depreciation	Outcome 1	0.185	0.0185	800	0.6	0.185	0.037	800	0.6	0.185	0.06	0	1	
	Outcome 2	0.63	0.0185	1000	0.5	0.63	0.037	1200	0.4	0.63	0.06	20	0.99	
	Outcome 3	0.185	0.0185	1500	0.25	0.185	0.037	1500	0.25	0.185	0.06	100	0.95	
CE of EM			0.0087				0.015				0.05			0.6648
6. BUILDER	Outcome 1	0.185	0.0185	500	0.75	0.185	0.037	500	0.75	0.185	0.06	1500	0.25	
	Outcome 2	0.63	0.0185	1000	0.5	0.63	0.037	1000	0.5	0.63	0.06	1700	0.15	
	Outcome 3	0.185	0.0185	1500	0.25	0.185	0.037	1500	0.25	0.185	0.06	2000	0	
CE of EM			0.0093				0.018				0.01			0.5337
7. Renewal	Outcome 1	0.185	0.0185	400	0.8	0.185	0.037	400	0.8	0.185	0.06	500	0.75	
Factors	Outcome 2	0.63	0.0185	500	0.75	0.63	0.037	500	0.75	0.63	0.06	1000	0.5	
	Outcome 3	0.185	0.0185	700	0.65	0.185	0.037	700	0.65	0.185	0.06	1500	0.25	
CE of EM			0.0137				0.027				0.03			0.3869
8. AME	Outcome 1	0.185	0.0185	300	0.85	0.185	0.037	300	0.85	0.185	0.06	1000	0.5	
	Outcome 2	0.63	0.0185	500	0.75	0.63	0.037	500	0.75	0.63	0.06	1500	0.25	
	Outcome 3	0.185	0.0185	800	0.6	0.185	0.037	800	0.6	0.185	0.06	2000	0	
CE of EM			0.0137				0.027				0.01			0.5887

CE Data for Alternatives 9-15: Uncertain EMs and CE of Alt

R= **0.269**		**DoD**				**PM**				**Base**				**CE of**
Alternative		**Prob.**	**Weight**	**Score (X)**	**Value**	**P**	**W**	**X**	**V**	**P**	**W**	**X**	**V**	**Alt**
9. FRM	Outcome 1	0.185	0.0185	50	0.975	0.185	0.037	100	0.95	0.185	0.06	5	0.9975	
	Outcome 2	0.63	0.0185	100	0.95	0.63	0.037	200	0.9	0.63	0.06	20	0.99	
	Outcome 3	0.185	0.0185	200	0.9	0.185	0.037	300	0.85	0.185	0.06	30	0.985	
CE of EM			0.0175				0.033				0.05			0.5963
10. FMM	Outcome 1	0.185	0.0185	50	0.975	0.185	0.037	200	0.9	0.185	0.06	10	0.995	
	Outcome 2	0.63	0.0185	150	0.925	0.63	0.037	250	0.875	0.63	0.06	50	0.975	
	Outcome 3	0.185	0.0185	200	0.9	0.185	0.037	300	0.85	0.185	0.06	90	0.955	
CE of EM			0.0172				0.032				0.05			0.6900
11. Bottom Up	Outcome 1	0.185	0.0185	10	0.995	0.185	0.037	20	0.99	0.185	0.06	50	0.975	
	Outcome 2	0.63	0.0185	20	0.99	0.63	0.037	50	0.975	0.63	0.06	500	0.75	
	Outcome 3	0.185	0.0185	50	0.975	0.185	0.037	100	0.95	0.185	0.06	700	0.65	
CE of EM			0.0183				0.036				0.04			0.5000
12. Q-Factors	Outcome 1	0.185	0.0185	10	0.995	0.185	0.037	20	0.99	0.185	0.06	1500	0.25	
	Outcome 2	0.63	0.0185	20	0.99	0.63	0.037	50	0.975	0.63	0.06	1700	0.15	
	Outcome 3	0.185	0.0185	50	0.975	0.185	0.037	100	0.95	0.185	0.06	2000	0	
CE of EM			0.0183				0.036				0.01			0.6394
13. Alt FRM	Outcome 1	0.185	0.0185	100	0.95	0.185	0.037	200	0.9	0.185	0.06	30	0.985	
	Outcome 2	0.63	0.0185	150	0.925	0.63	0.037	250	0.875	0.63	0.06	50	0.975	
	Outcome 3	0.185	0.0185	300	0.85	0.185	0.037	400	0.8	0.185	0.06	70	0.965	
CE of EM			0.017				0.032				0.05			0.6552
14. Alt FMM	Outcome 1	0.185	0.0185	50	0.975	0.185	0.037	200	0.9	0.185	0.06	10	0.995	
	Outcome 2	0.63	0.0185	150	0.925	0.63	0.037	250	0.875	0.63	0.06	50	0.975	
	Outcome 3	0.185	0.0185	200	0.9	0.185	0.037	300	0.85	0.185	0.06	90	0.955	
CE of EM			0.0172				0.032				0.05			0.7177
15. H-Model	Outcome 1	0.185	0.0185	500	0.75	0.185	0.037	500	0.75	0.185	0.06	1500	0.25	
	Outcome 2	0.63	0.0185	1000	0.5	0.63	0.037	1000	0.5	0.63	0.06	1700	0.15	
	Outcome 3	0.185	0.0185	1500	0.25	0.185	0.037	1500	0.25	0.185	0.06	2000	0	
CE of EM			0.0093				0.018				0.01			0.7859

References

Adams, Jonathan & Mercer, Stephen. (Feb 2007). *A Comparison of DoD and Industry Recapitalization,* LMI Government Consulting, DoD Report CE502T1

Bar-Yosef, Sasson and Lustgarten, Steven. (1994). Economic Depreciation, Accounting Depreciation, and Their Relation to Current Cost Accounting, Journal of Accounting, Auditing & Finance, 9: 41-60.

Barco, A. L. (1994). Budgeting for facility repair and maintenance. *Journal of Management in Engineering, 10*(4), 28-34.

BRB - Building Research Board. (1991). National Research Council (Ed.), *Pay now or pay later: Controlling the cost of ownership from design throughout the service life of public buildings*. Washington DC: National Academy Press.

BRB - Building Research Board. (1998). In National Research Council (Ed.), *Stewardship of federal facilities: A proactive strategy for managing the nation's public assets*. Washington DC: National Academy of Sciences.

Christian, J., & Pandeya, A. (1997). Cost predictions of facilities. *Journal of Management in Engineering, 13*(1), 52-61.

Clemen, Robert, T. & Reilly, Terence. (2001). *Making Hard Decisions*, Duxbury Press, CA

DoD. (1989). *Renewing the built environment.* Washington DC

DoD. (2002). *Facilities recapitalization front-end assessment.* Department of Defense.

DoD. (2006). Budget Models Used for Base Operations Support, Sustainment, and Facilities Recapitalization. Report to Congress, Deputy Under Secretary of Defense.

DoD Briefing. (2007). Facilities Modernization Model, HQ Department of Defense, Washington DC, September 2007.

Earl, R. W. (1997). The condition assessment survey: A case study for application to public sector organizations. *Infrastructure Condition Assessment; Art, Science, and Practice*, 277-286.

Esenbach, Ted G. (2003). *Engineering Economy – Applying Theory to Practice*. New York: Oxford University Press.

Fraumeni, Barbara M. (July 1997). The Measurement of Depreciation in the U.S. National Income and Product Accounts, *Survey of Current Business*.

GAO. (1997). *Deferred maintenance: Reporting requirements and identified issues* No. GAO/AIMD-97-103R). Washington DC: U.S. General Accounting Office.

GAO. (1999). *Military infrastructure: Real property management needs improvement* No. GAO/NSAID-99-100). Washington DC: U.S. General Accounting Office.

GAO. (2000). *Military real property maintenance: Management improvements are needed to ensure adequate facilities* No. GAO/T-NSAID-00-111. Washington DC: U.S. General Accounting Office.

Geldermann, D., & Sapp, D. (March 2007). Streamlining facility condition assessments. [Electronic version]. *Buildings 101, 3:* 52-53.

Green, C. D., Grinyer, J. R., and Michaelson, R. (2002). A Possible Economic Rationale for Straight line Depreciation, Abacus. 38: 91-120.

Guy, Bradley (2006). The optimization of building deconstruction for Department of Defense Facilities: Ft McClellan Deconstruction Project. *International Journal of Environmental Technology and Management*, 6: 386-404.

Jefson, Matt P. (2005). *Dynamic modeling and evaluation of recurring infrastructure maintenance budget determination methods.* MS Thesis. Air Force Institute of Technology, Wright Patterson Air Force Base, OH, School of Engineering and Management. (ADA435189).

Jeoun, Jimmy. (March 2005). Using value-focused thinking to evaluate the practicality of ground-source heat pumps at military installations. MS Thesis, Air Force Institute of Technology, Wright Patterson Air Force Base, OH, School of Engineering and Management. (AFIT/GEM/ENS/05M-01).

Kaiser, H. H. (1995). Preventing deferred maintenance. *AIPE Facilities: The Journal of Plant and Facilities Management & Engineering,* 24-31.

Keeney, Ralph, L. (1992). *Value-Focused Thinking: A Path to Creative Decisionmaking*, Harvard University Press, Cambridge, MA.

Kirkwood, Craig W. (1997). *Strategic Decision Making: Multiobjective Decision Analysis with Spreadsheets,* Duxbury Press, CA.

Lemer, A. C. (1996). Infrastructure obsolescence and design service life. *Journal of Infrastructure Systems, 2*(4), 153-161.

Leslie, S. E., & Minkarah, I. A. (1997). Forecasts of funding needs for infrastructure renewal. *Journal of Infrastructure Systems, 3*(4), 169-176.

Lufkin, P. S., Desai, A., & Janke, J. (2005). Estimating the restoration and modernization costs of infrastructure and facilities. *Public Works Management & Policy, 10*(1), 40-52.

Neely, E. S., & Neathammer, R. (1991). Life-cycle maintenance costs by facility use. *Journal of Construction Engineering and Management, 117*(2), 310-321.

Ottoman, G., R., Nixon, B. W., & Chan, Y. (1999). Budgeting for facility maintenance and repair. II: Multicriteria process for model selection. *Joural of Managment in Engineering, 15*(4), 84-95.

Ottoman, G., R., Nixon, B. W., & Lofgren, S. T. (1999). Budgeting for facility maintenance and repair. I: Methods and models. *Journal of Management in Engineering, 15*(4), 71-83.

Ottoman, G. R. (1997). *Forecasting methodologies for USAF facility maintenance and repair funding requirements.* MS Thesis. Air Force Institute of Technology, Wright Patterson Air Force Base, OH, School of Engineering and Management. (ADA334347).

Rugless, J. M. (1993). Condition assessment surveys. *AIPE Facilities: The Journal of Plant and Facilities Management & Engineering, 20*, 11-13.

Schmalz, T. C. and Stiemer, S. F. (Aug 1995). Consideration of Design Life of Structures, *Journal of Performance of Constructed Facilities*, 9:206-219.

Sharp, Christopher, L. (Aug 2002). *An Evaluation of Facility Maintenance and Repair*. MS Thesis. Air Force Institute of Technology, Wright Patterson Air Force Base, OH, School of Engineering and Management. (AFIT/GEE/ENV/02-19).

Sherman, D. R., & Dergis, W. A. (1981). A funding model for building renewal. *Planning For Higher Education, 9*(3), 21-25.

Shoviak, M. J. (2001). *Decision analysis methodology to evaluate integrated solid waste management alternatives for a remote Alaskan air station.* MS Thesis, Air Force Institute of Technology, Wright Patterson Air Force Base, OH, School of Engineering and Management, (AFIT/GEE/ENV/01M-20).

Taubman, Paul, and Rasche, Robert. (Sep 1969). Economic and Tax Depreciation of Office Buildings, *National Tax Journal*, 22: 334-346.

USACE. (1994). *Issues in deferred maintenance* , No. IWR Report 94-FIS-16, US Army Corps of Engineers, Federal Infrastructure Strategy Program.

Uzarski, D. R., & Burley, L. A. (1997) *Assessing building condition by the use of condition indexes.* Boston, MA.

Vanier, D. J. (2001). Why Industry Needs Asset Management Tools, *Journal of Computing in Civil Engineering*, 15: 35-43.

Weir, Jeffery. (2007). Hierarchy Builder_New, Microsoft Excel Macro for VFT Analysis, WPAFB, OH: AFIT.

Vita

Captain Krista Hickman graduated from Petoskey High School in Petoskey, MI in 1997. She attended Embry-Riddle Aeronautical University in Daytona Beach, FL, and graduated in December 2001 with a Bachelor of Science degree in Civil Engineering. She commissioned as a Second Lieutenant in December 2001 through the Reserve Officer Training Corps, Detachment 157.

Her first assignment was to the 15 Civil Engineer Squadron at Hickam AFB, HI where she started as the Base Community Planner and eventually became the Chief of Base Development in the Engineering Flight. While at Hickam AFB, she deployed to Osan AB, Republic of Korea in February 2002 with a team of 20 craftsmen to build, maintain, and tear down a tent city in support of a peninsula-wide exercise. In September 2005, she transferred to the Pacific Air Forces Headquarters to manage a project to bed-down a new headquarters function and renovate the headquarters facility.

In September of 2007 she entered the Graduate School of Engineering and Management, Air Force Institute of Technology, Wright-Patterson AFB, OH. Upon graduation, Captain Hickman will transfer to the Civil Engineer and Services School at Wright-Patterson AFB, OH to be an instructor.

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14. ABSTRACT The purpose of this research was to develop a decision tool to assist in the evaluation of facility recapitalization budget estimation models to determine which model was best suited for a particular organization. Specifically, this thesis sought to answer an overarching research question addressing the importance of recapitalization and the best method to estimate the facility recapitalization budget using the Department of Defense (DoD) as the subject of the research. A comprehensive literature review revealed ten existing recapitalization model alternatives to consider for implementation. The methodology used to develop a decision tool was based on the Value Focused Thinking (VFT) approach. A panel of recapitalization program managers developed a value hierarchy to evaluate all potential recapitalization model alternatives. The results of the deterministic and probabilistic analyses of 15 alternatives found that the proposed DoD model scored well in comparison to other alternatives. With slight modifications to the model according to the value hierarchy, the DoD can improve the performance of their recapitalization models. The H-Model, created specifically for this analysis, dominated all other alternatives and is recommended for implementation.						
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